REMOTE SENSING RESEARCH PROGRAM
DEPARTMENT OF FORESTRY AND CONSERVATION
COLLEGE OF NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA, BERKELEY

Final Report

for

USFS Coop Agreement No. 16-640-CA

DEVELOPMENT OF SAMPLING DESIGNS TO USE WITH REMOTELY SENSED DATA FOR NATIONAL RESOURCES INVENTORIES

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BERKELEY, CALIFORNIA 94720

13 June 1977

Mr. Robert C. Aldrich
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Dear Bob:

As required by the terms of research agreement 16-640-CA, with the University of California, please find enclosed the final project report. Delivery of the report coincides with an oral presentation of results at a meeting in Portland, Oregon, on 13 and 14 June 1977.

All data files and program lists have been maintained as permanent files under account number 804259 at the Lawrence Berkeley Laboratory, Computer Center. There are also several magnetic tape files available from the Remote Sensing Research Program, UC, Berkeley. A list of files is included as an appendix to the report.

Sincerely,

Lee C. Wensel
Co-Investigator

Robert N. Colwell
Co-Investigator

Stephen J. Titus
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ABSTRACT

This report documents procedures, results, and recommendations for modifying sample survey systems implemented by the U.S. Forest Service to assess renewable natural resources at the national and regional level. Western Washington is the regional area to which the study was addressed. Particular emphasis is given to the role of remote sensing data sources as inputs to both the design and implementation phases of surveys to provide information used in making resource assessments. All data files and programs used in this analysis have been maintained as permanent files available under Forest Service accounts at the Lawrence Berkeley Laboratory, Computer Center. Several magnetic tape files are maintained by the Remote Sensing Research Program, U.C. Berkeley.

ACKNOWLEDGEMENTS

Data and technical assistance was made available to the University of California by several agencies. Special acknowledgement of these services is appropriate.

The U.S. Forest Service provided data utilized in several parts of the study. The efforts of Dan Oswald and Colin MacLean were significant in arranging for timely arrival of needed data and technical information on current Forest Service procedures.

The Washington State Department of Natural Resources provided the aerial photography used in Figures 7 and 8. Roger Harding and Tom Scott provided useful background on the technical procedures in the DNR/PNRC remote sensing study.

ESL Inc. Sunnyvale, California, made a significant effort to provide digital satellite data, as well as statistical summaries for the different classes, at a time when this data would not have been routinely available. Special thanks are due to Dennis Noren, Jim Nichols, and Bob DeZur.

Quality photographic work was provided by Steve Harui, Remote Sensing Research Program, UCB.

Robin Filion, provided considerable assistance in a variety of contexts and was instrumental in acquiring, evaluating, and summarizing the numerous references consulted in assembling the annotated bibliography.

Finally, but certainly not least, thanks are due to the numerous computer programmers who have helped handle the data and make necessary modifications to the various programs. Thanks to William Senkus who did much of the original programming for the WILLIAM package. Without his good documentation and organization, modifications could have been much more difficult. George Vasick, of the Remote Sensing Research Program, UCB, together with Peter Wood and others in the Computer Science and Applied Mathematics Department, Physics, Computer Science and Mathematics Division, the Lawrence Berkeley Laboratory, also made substantial contributions to the project.

FORWARD

Cooperative research agreement 16-640-CA between the U.S. Forest Service and the Remote Sensing Research Program, Department of Forestry and Resource Management, University of California, Berkeley was undertaken to develop new or modified sampling systems, using remotely sensed data, for national and regional level inventories of natural resources. The agreement was actually funded by the Resources Evauation Techniques Group at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. However, significant interaction was needed with the Resources Evaluation Unit of the Pacific Northwest Forest and Range Experiment Station in Portland, Oregon, since that unit would be concerned with implementation of any recommended changes. In addition, the test site to be studied was in western Washington.

The investigation by the University centered on

1) a review of current information needs and the operating context
2) a review of potential remote sensing data sources
3) an analysis of several specific alternative approaches to sampling a test site located in western Washington

The purpose of this report is to present the results of the study, primarily recommendations and ways to enhance the current survey procedures. In addition, the technical analysis procedure including the WILLIAM software package, is documented and implementation of the recommendations is addressed.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The basic objective of this study is to identify, evaluate, and summarize potential modifications to the current Forest Survey. The methodology for evaluating opportunities is based primarily on implementation of a survey design planning system, developed at the University of California, which utilizes satellite and other data sources to create a population representation.

A 515,000 acre portion of Gray's Harbor County in western Washington was used as a representative test site. Through the use of the planning model a number of alternative sampling systems were evaluated with the objective being to identify the alternative that has the smallest implementation cost while still meeting precision constraints for each of three estimators. The results of this analysis indicated several possibilities for cost reduction in Forest Survey activities.

Major recommendations are (See Sections 7.0 - 7.3 for details):

1) Reliance on other agencies for basic measurement data to be incorporated in estimates of resource parameters should be minimized.
2) A formal planning mechanism should be implemented, by inventory unit, to take better advantage of available propulation data.
3) All lands regardless of their management or political status should be included in the population to be sampled.
4) Stratification should be maintained and updated over time rather than starting over at each new inventory.
5) Current Forest Service procedures use a small 10 point cluster sample unit. Larger cluster sample units, on the order of several hundred acres could be used in conjunction with two stage sampling to reduce total survey cost and permit evaluation of treatment and management opportunities as they occur within, and are affected by surrounding vegetation and land use patterns. Additional improvements may, under certain circumstances, be made by including double sampling within the second stage units so that additional remote sensing data could be incorporated.
6) Since primary sample unit (PSU) sizes are likely to vary from one sample unit to another, a proportional-to-size selection scheme using size of PSU will further reduce cost.
7) Measurements and field procedures for individual plots will not be significantly affected unless, or until, double sampling procedures are considered.

Implementation considerations include the following (See Section 8.1 for details):

1) Carrying out all data acquisition activities will require restructuring and perhaps increasing the size of the field data collection efforts. There are, however, several possibilities for working cooperatively with agencies which might benefit from some of the data derived.
2) The planning activity will require training of personnel in the use of the new techniques for evaluating sampling alternatives. A complementary effort is needed to ensure availability of data on prior forest conditions.
3) Stratification would be readily available as a result of 2) above.
4) Two stage sampling of clusters should result in more efficient collection of field data than the current 3.4 mile square grid. Actual measurement procedures on individual plots would not necessarily have to change.

DEVELOPMENT OF SAMPLING SYSTEMS TO USE WITH

REMOTELY SENSED DATA FOR NATIONAL RESOURCES

INVENTORIES

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1.0 INTRODUCTION

The purpose of this report is to present the results of a study to identify and evaluate opportunities for enhanging current survey activities by the U.S. Forest Service in light of new requirements by the Resource Planning Act (RPA). The specific recommendations are given as well as documentation of the technical analysis procedures. In addition implementation considerations are addressed for the major recommendations.

Remaining sections in this chapter 1) discuss the inventory problem, 2) outline the objectives and scope of the Study, 3) provide an overview of the study plan and experimental procedure used, and 4) summarize major recommendations. Subsequent chapters deal in more depth with 1) information needs and constraints 2) current data acquisition activities and methods, as they relate to western Washington and 3) a review of remote sensing applications in sampling natural resources. With this background enhancement opportunities are identified, analyzed using available data, and evaluated according to several criteria. Recommendations are made on the basis of this analysis, and a final chapter considers implementation, research needs, and the longer term problem of data management as it relates to sample surveys.

1.1 The Inventory Problem

The Forest Service has been delegated the responsibility for making an inventory of the present and prospective condition of the renewable resources of the forest and rangelands of the United States. This inventory is authorized by the McSweeney-McNary Act of 1928 and the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974. Present resource inventory procedures are fragmented within and among natural resource agencies and between resource functions. National timber supplies on over 500 million acres of commercial forest land are now inventoried approximately every 10 years (Forest Servey). For these statewide and regional inventories, efficient sampling designs were developed from over 40 years of experience. They now meet national inventory goals. However, an inventory of the more than 1.5 billion acres of commercial and non commercial forest and range lands, in the time frame set by the RPA, will require a much greater effort and a more efficient use of both remotely-sensed and directly-measured data.

The problem, then, is to develop sample survey systems which make the best possible use of all auxiliary data in meeting these new requirements. In addition the systems developed must work within the organizational and technical constraints under which the Forest Service operates and meet multiresource information needs. Since the informational requirements, the measurement opportunities, and costs involved will likely change as the survey agency undertakes changes in the basic sampling design, it is recognized that the analysis procedure developed in this study (i.e., the planning model) is as important as the specific recommendations that are described herein.

It is in this context that the Remote Sensing Research Program at the University of California undertook this study.

1.2 Objectives and Scope of the Study

The basic objective of this study is to identify, evaluate and summarize possible enhancements to Forest Survey procedures currently used for evaluation of timber resources for national planning. Enhancement opportunities are viewed in a multiresource estimation context. Secondary objectives include assisting in the implementation of any procedures which might be incorporated into the Forest Survey, and beginning the development of a broader approach to data structure and inventory design problems to meet the broader informational needs implied by the RPA.

These objectives have been identified based on constraints of time and resources available for the current research effort and the operational factors. that limit the Forest Survey effort in the Western Washington test site to relatively minor (at least in terms of cost) short term modifications. Even in considering short term enhancements it is difficult to ignore the long term implications of information needs and organizational structure. The approach taken, for the short term, is based on the assumption that Survey's primary orientation will be towards regional-level statistics. In the long term however, it seems likely that the trend will be towards more and more detail in the data and information requirements. If this occurs there will likely be a need to rely increasingly on data sources from many agencies in spite of the coordination problems. Ultimately, there may be activities with both regional emphasis as well as supplementary activities with a much more local outlook.

The test site for the study is Western Washington, consisting of the 38 counties lying west of the Cascade Mountain summit. This area is to be surveyed in the 1978 field season and planning for that survey will occur at an ideal time for consideration of possible enhancements to current procedures. The 38 county area is 15,843,000 acres (6,411,000 hectares) with approximately 80 percent of the area in forest land and approximately 60 percent in commercial forest land. There are approximately 690 townships, 24,750 sections, 400,000 40-acre parcels, and 1,584,000 10-acre parcels. The 10-acre figure is interesting because of its relationship to the cell size that is used in the Washington, DNR information system to be discussed later. In meteric units there are 64,110 square kilometers, 1,502,860 4-hectares (10 acres) blocks, and 256,460 25-hectare (60 acres) blocks.

Land use data is based on 1970 Forest Service results and is summarized in Table 1.

At least four major geographic reference systems could be used for referencing areas in a consistent fashion including 1) the rectangular survey, 2) the state plane system (feet), 3) the UTM system (metric and all within grid zone) 10, and 4) geographic coordinates.

1.3 Study Plan and Experimental Procedure

A study plan for the project was prepared and is included as Appendix A. It identifies three major tasks and several subtasks and provides the starting point from which the experimental procedure was developed. Task I deals with identification of informational needs and organizational constraints and was a necessary activity prior to considering enhancement opportunities (Task II). The procedures used currently by several agencies were reviewed in depth as they represented potential data sources for the evaluation of sampling opportunities. In addition an annotated bibliography of publications since about 1970 was prepared to summarize current applications of remotely sensed data within a sample survey framework.

TABLE 1. WESTERN WASHINGTON (1970) LAND USE SUMMARY

	(000) Acres	Percent							
Forest Land	12,743	80.43	Deferred	55	0.35				
			Unproductive	1624	10.25				
			Prod. Reserved	1073	6.77				
			CFL	9991	63.06	State	1379	8.70	
						County & Muni	163	1.03	
				12743	80.43	Private	5868	37.04	Industry 3598 22.71
									Farmer 437 2.76
									Misc. 1833 11.57
									5868 37.04
						Federal	2581	16.29	NFS 2321 14.65
							9991	63.06	BLM 2 0.01
									BIA 190 1.20
									Misc. 68 0.43
									2581 16.29
Crop Land	769	4.85							
Other Land	2331	14.72							
	15843	100.00	Pasture						
			Range			→ essentially none in Western Washington			
			Swamp			Breakdown not available			
			Urban-Ind.						
			Other Non-forest						

Since any evaluation of opportunities ultimately must be tied to a particular population and set of cost assumptions, and since one opportunity for enhancement of current procedures is to implement a planning mechanism for each inventory unit, it was decided to identify a specific test site within the western Washington area which would be representative of the entire study area. An area of approximately 515,000 acres was selected in Gray's Harbor County on the Washington Coast. Further since the objective of a planning phase is to evaluate alternatives and to determine how to best allocate effort for a given sampling system, the analysis of alternative enhancement opportunities may be viewed as an elaborate planning phase which both serves the analysis task and demonstrates a procedure for systematically utilizing available population and cost data to efficiently allocate sampling effort. The analysis procedure itself uses satellite multispectral data in combination with supplementary data on the variables to be estimated by the sample survey. It is based on procedures developed at the University of California (Colwell and Titus, 1976; Titus and Wensel 1977), and incorporates several added capabilities not present in the original model.

1.4 Summary of Major Recommendations

The major recommendations are summarized here:

1.) Reliance on other agencies for data to be incorporated in estimates of resource parameters should be minimized. While not justified by cost considerations alone, problems of special handling and analysis as well as lack of control over quality, completeness and timeliness of data lead to a number of unevaluated sources of error in estimates. The cost of acquiring this additional data could be minimized by cooperating with the agencies which could likely use some of the data for their own needs. In addition it would be useful to include in the population to be sampled all resource lands including those reserved or in park status.

2.) A formal planning and design phase should be implemented by inventory unit to take advantage of the information accumulated through repeated surveys. This implies a planning mechanism such as that used for this study as well as an associated requirement to develop and maintain an accessible data structure for each inventory unit. A parallel research effort should be implemented to continue development of the planning system and to incorporate the results of new findings into the operational efforts. Cooperative efforts with state agencies such as DNR may be especially useful in combining efforts to develop and maintain information.

3.) Stratification should be made based on information available from a data source which is maintained over time. One possibility is the data base available from DNR and based on satellite multispectral data. Several strategies for stratification could be used. In the current study of stratification based on available data was implemented using the "ISOCLASS" clustering algorithm. Results were not totally conclusive since the procedure for using this technique was developed as part of the study and there was little time for additional work using this approach. However this approach appears promising and further testing and evaluation would be desirable.

4.) Larger cluster sampling units, on the order of several hundred acres, could be used in conjunction with two stage sampling to reduce total cost as well as permit evaluation of treatment and management opportunities as they occur within and are affected by surrounding vegetation and land use patterns.

5.) Eventually the two stage design of (4) should be enlarged to include double sampling within the second stage units so that additional remote sensing data could be incorporated to reduce the number of field plots needed.

6.) Since primary sample unit (PSU) sizes are likely to vary, a probability proportional-to-size (PPS) selection scheme using size of PSU will reduce cost further.

7.) Measurements and field procedures will not be significantly affected unless, or until, double sampling procedures are considered. In that instance the field and auxiliary measurements must be of the same physical areas.

Implementation considerations include the following:

1.) Carrying out all data acquisition activities will require restructuring and perhaps increasing size of the field data collection activities. There are, however, several possibilities for working cooperatively with agencies which might benefit from some of the data derived.

2.) The planning activity will require training of personnel in the use of the new techniques for evaluating sampling alternatives as well as associated need to have available the data on prior forest conditions.

3.) Stratifications would be readily available as a result of 2) above.

4.) Two stage sampling of clusters should result in more efficient collection of field data than the current 3.4 mile square grid. Actual measurement procedures would not necessarily have to change.

2.0 FOREST SURVEY INFORMATION NEEDS AND CONSTRAINTS

2.1 Current Forest Survey Context

The current scope of Forest Survey activities includes all commercial forest land regardless of ownership. However, for purposes of estimating area in commercial forest land the initial survey activities deal with a larger class of land including all ownerships and uses, with certain exceptions. These exceptions typically include national parks and other productive reserved lands, national forests, and Bureau of Land Management lands. Reserved lands are not included in any analysis; NFS and BLM lands are surveyed by those groups and data is made available to Forest Survey for analysis.

The primary objective of the Forest Survey is to provide timber resource statistics for use in national level planning. Basic parameters of interest relate to current values and change since the last evaluation. Specifically, estimates are provided for areas, volumes, growth, removals and mortality by various subdivisions including ownership, size class, species group, and region.

Information production methods vary from region to region and include some other complicating factors beyond sampling. Since several agencies are providing data which must be combined, special techniques are often required to combine the data into one estimate. In addition, since Forest Survey has no direct control over the other data gathering activities there is no guarantee that all required data is collected. In addition there is the problem of updating all data to a common point in time. In the recent Douglas County Oregon inventory the various inventories by the Forest Survey, the NFS and BLM covered a 10-year period in time. Further, since within NFS there may be variability as methods and measurement conventions change, the problems of updating, and combining all the varied data can be substantial.

In addition to the methodological difficulties are budget and other constraints which limit control and the ability of the Forest Survey personnel to work towards resolution of some of these difficulties. The recent RPA legislation has several implications for expanded Forest Survey activities; however, at this point in time no additional funds have become available for taking up the additional responsibilities.

2.2 RAP, Short Term Implications

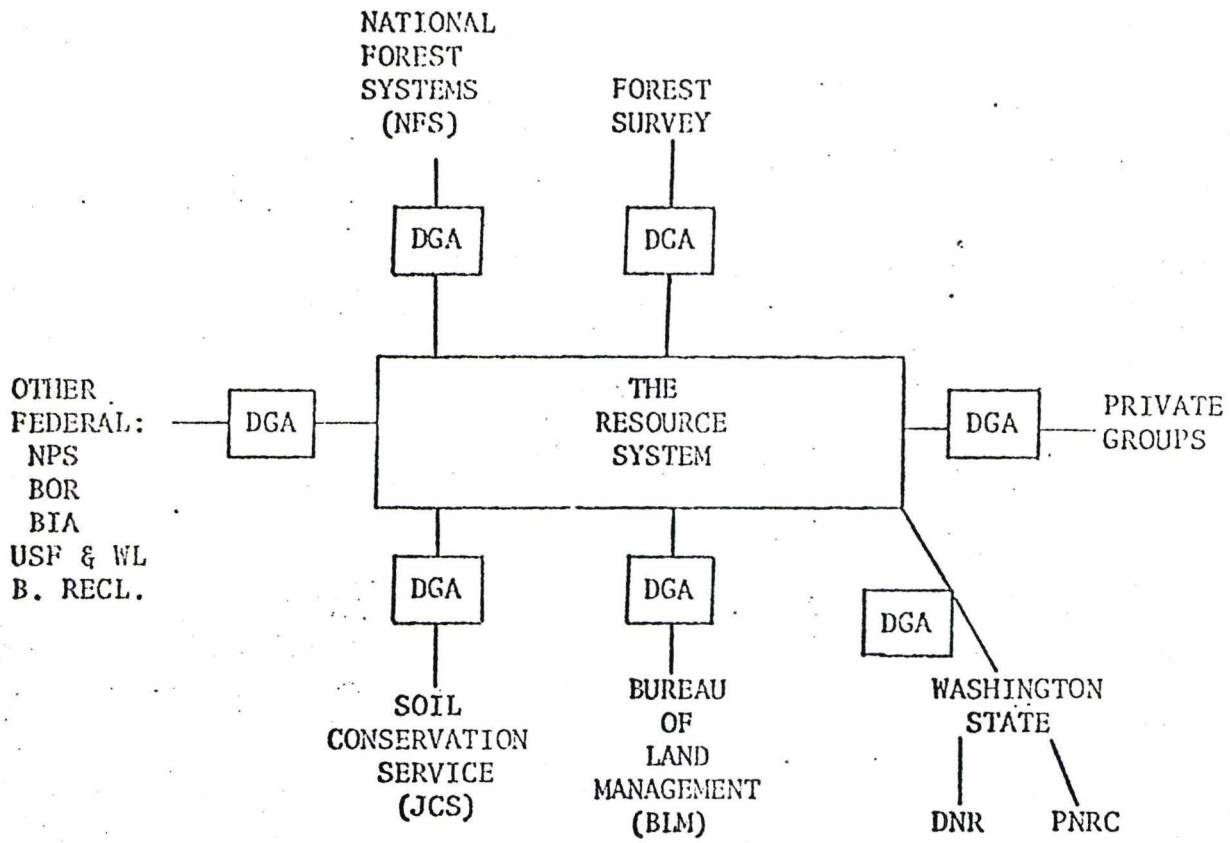
At least two major short term consequences of the RPA have been identified. First, a broader view of resource parameters is needed in current Forest Survey activities, and second, the cycle time for reinventory will be shorter than in the past. Both of these items are reflected in this study since both forest and range parameters, and perhaps others as well, are of interest. One opportunity in considering modifications to Forest Survey is the possibility that enhancements may lead to a shorter cycle time for reinventory.

2.3 RPA, Longer Term Implications

In the longer term, the need for a coordinated interagency effort to consolidate and manage information acquisition, maintenance, and handling functions is obvious. With such a commitment duplication of effort could be minimized and information needs for multi-resource analysis of policy and management opportunities could be met in a coordinated manner. Presently, while there is still a need for new data, substantial problems exist just in coordinating and managing currently available data sets.

Figures 1 and 2 show schematically the current and desired data and information management activities as they relate to the various agencies. Politically this kind of coordination may be difficult or impossible to achieve, but to identify this goal seems important since ultimately in many cases management and policy decisions should transcend arbitrary geographic or discipline responsibilities. There is an added complication resulting from the difficulties of incorporating the private sector without infringing on rights of privacy or appearing to promote governmental regulation of private affairs.

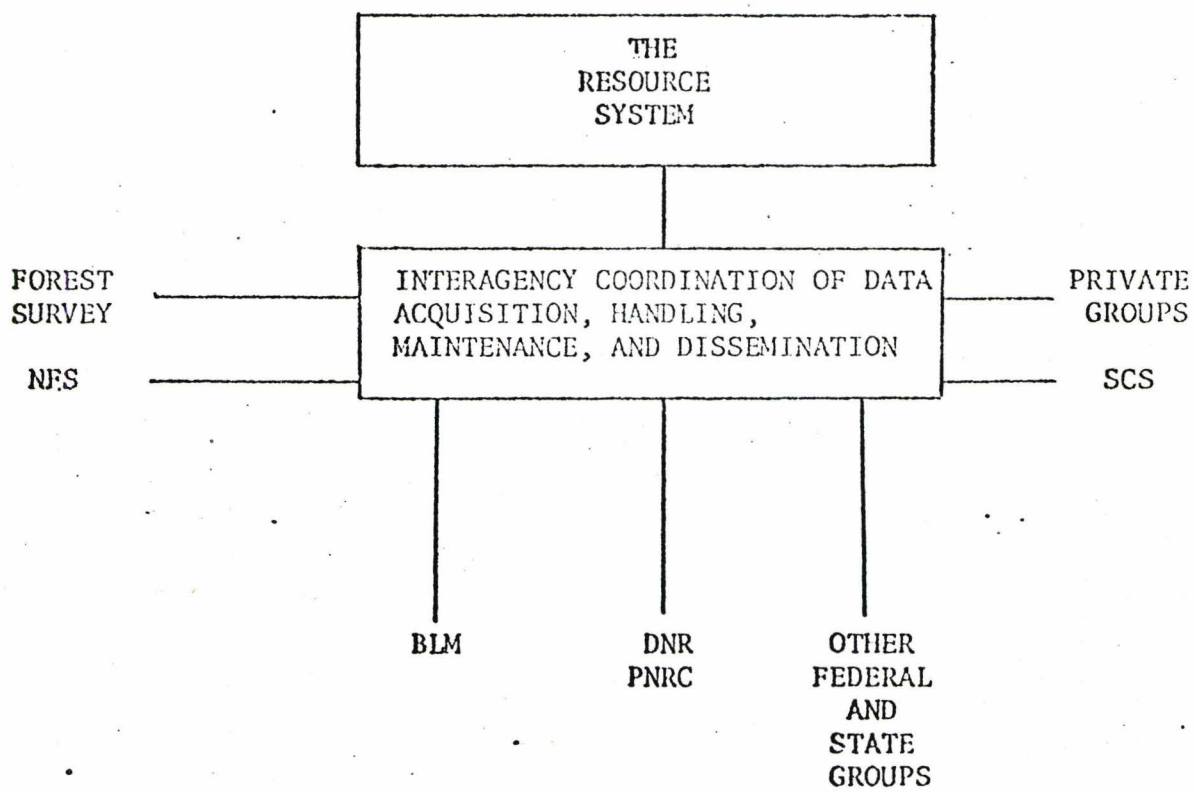
Figure 1. Current relationships between data acquisition activities and management groups for Western Washington



LEGEND:

DGA	Data Gathering Activities
DNR	Department of Natural Resources
PNRC	Pacific Northwest Regional Commission (Dept. of Commerce)
NPS	National Park Service
BOR	Bureau of Outdoor Recreation
BIA	Bureau of Indian Affairs
USF & WL	US Fish and Wildlife Service
B. Recl.	Bureau of Reclamation

Figure 2. Desired relationships between data acquisition activities and management groups for Western Washington



3.0 CURRENT DATA ACQUISITION ACTIVITIES

In preparation for identifying and analyzing alternative enhancement opportunities for the Forest Survey in western Washington it is important to understand and summarize the current survey activities by the major agencies in this area. Four agencies are involved in acquisition of data which is of interest to Forest Survey: 1) the Forest Survey unit itself, 2) the National Forest System in Region 6, 3) the Bureau of Land Management, and 4) the Washington State Department of Natural Resources.

3.1 Forest Survey

An outline of current Forest Survey procedures is included as Appendix B. Several important points however, need to be summarized.

The Forest Survey unit itself acquires only a part of the data which ultimately leads to the resource estimates and summaries. Depending on specific ownership patterns, the National Forest System and the BLM may provide substantial amounts of data. Forest Survey relies completely on data acquired by these agencies to fill the needs of Forest Survey. Since the survey unit has no real control over the activities of these other agencies, and this data is often acquired as part of other data acquisition activities, incomplete and non-standard data often results. In order to incorporate this data into the Survey format, substantial data manipulation and special analysis procedures may be required.

Currently, Forest Survey resource summaries are exclusively timber oriented. Some additional data is recorded in both the field and the photo interpretation phases relating to terrain features, but this data is not summarized.

The sampling procedure as described is a "double sampling for stratification" system with systematic location of a large sample of plots on photographs of varying scales, types, and dates. Stratification data is interpreted from these photo plots. The field plots are, however, located on a systematic basis independently of the land use stratification; hence there is no effective control on allocation of field plots over strata. With a large sample size it may be argued that this procedure will approach "proportional to area" allocation of sample units among strata; however, the statistical analysis procedure should treat the procedure as a post-stratification scheme. Current analysis procedures apparently follow the "double sampling for stratification" procedure rather than the "post stratification" procedure as actually implemented. This problem together with other possible shortcomings of the stratification scheme (as identified by the recent study plan for Forest Survey modifications prepared by the PNW Forest Survey unit) indicates that further investigation of a stratification procedure and its implication is desirable.

In addition, since field plot allocation is systematic based on a region wide grid size (3.4 miles), there is no opportunity for tailoring allocation to specific local conditions which influence both the sample size and allocation requirements to achieve a desired proecision objective. As prior information and data becomes increasingly available, it is important to spend time evaluating sample size requirements so that over-sampling does not occur. This is especially important if the time required for Survey activities becomes more limited.

3.2 NFS Inventory Procedures

NFS procedures vary widely from region to region and even within a region, where the inventory process may be evolving on a continuing basis. California is a good example of this process since a new compartment examination procedure was implemented there several years ago. This procedure will not be capable of providing the data required for Forest Survey. In Region 6, however, the procedure is more traditional and inventories of national forests follow the systematic line plot (1.7 mile grid) technique using the well established Forest Survey 10 point plot measurement procedure, with no stratification or other application of photo data sources. According to Briggs (R-6, USFS, Portland, Timber Management), this inventory procedure provides data for timber management planning as well.

3.3 BLM Activities

For the western Washington site, BLM ownership is less than one percent so the impact is small. For some areas, however, their ownership is large. BLM procedures for inventory apparently follow reasonably closely the 10 point plot procedure as used by Forest Survey and Region 6.

It should be noted that BLM is rapidly moving toward a substantially new data acquisition and handling system which will utilize remote sensing and complex data handling capabilities to a considerable extent. This activity could well have significant impacts on data acquisition for forest areas, which have up until now largely followed Survey procedures.

3.4 Washington, DNR-GRIDS

The GRIDS system is used by DNR for management planning on state owned lands (approximately 3 million acres). Information record units are 10 acre parcels of land. A general data base management and manipulation system has been developed for this data base. Data for each cell is based largely on interpretation of photos acquired by DNR. A small number of points are field checked for adequacy of the photo interpretation. In addition, special purpose field surveys are used to obtain more detailed management information on an as-needed basis. Information maintained includes detailed administrative and land use characteristics as well as vegetation and soils-topography data. Management treatments or other significant changes to particular areas are incorporated into the data base within 3 months of occurance.

3.5 Washington, DNR-PNRC Remote Sensing Study

In addition to its routine management of state-owned lands, DNR has an interest in state and regional level planning. DNR has worked with the Pacific Northwest Regional Commission (PNRC) of the Department of Commerce to evaluate Forest Productivity in Western Washington. In addition to that study is an on-going demonstration of the potential for inventory of forest lands using remote sensing and other techniques in a sample survey context. The study is funded jointly by PNRC and the NASA Ames Research Center with the project being conducted primarily by ESL, Incorporated, and DNR personnel. An outline of this study is included as Appendix C since it represents a substantial effort to incorporate various remote sensing data sources in the inventory of forest resources specifically for the Western Washington area. The DNR-PNRC study is significant because it offers substantial background data for this site and because of the variety of sampling and remote sensing techniques incorporated. The PNRC study as implemented does not address a number of parameters of interest to Forest Survey including growth, mortality and removals, but concentrates on basal area and volume (of old growth timber).

4.0 REMOTE SENSING APPLICATIONS TO SURVEYS OF NATURAL RESOURCES, A LITERATURE REVIEW

A review of literature devoted to applications of remote sensing to sample surveys of natural resources was conducted to document the scope of remote sensing possibilities identify any potential new uses for remote sensing data. The results are presented as an annotated bibliography (Appendix E). Annotations were made for most references according to the following topics:

1) sample design
2) measurement methods and equipment
3) data handling and analysis of variables, including precision achieved
4) costs
5) conclusions

Several references were summarized very briefly because of their general nature. These are included at the back of Appendix E.

The following paragraphs summarize the major trends in use of remotely sensed data.

In the past few years sample design has been of increasing interest to foresters. Various designs have been used including stratified cluster sampling (Bonner, 1975), and stratified multi-stage sampling (Aldred, 1973, Titus, 1977). Comparisons between different sampling designs have been made by Bonner (1973), and simulation models have been studied (Titus, 1977). One of the most interesting designs because of its potential applicability to multivariable sampling the the "grouping" method suggested by Poso (1972).

Black-and-white or color infrared photography, taken from fixed-winged aircraft, has been the most successful imagery (Bonner, 1973, Nielson, 1971). Comparisons of scale are numberous but a linear relationship between scale and efficiency has not been established for any population.

Strip photography (Aldred, 1975) is conducive to both cluster and multistage designs, and seems to be the most efficient sampling method. Plot size and shape within photo strips have been investigated by Sayn-Wittgenstein (Sayn-Wittgenstein, 1969).

The variables measured on aerial photos depend on whether tree or stand volume tables are to be accessed. Aldred, Bonner, and Sayn-Wittgenstein measured height and crown width or area to determine individual tree volumes. Regression equations were constructed of the general form

$$\text{Dbh} = a+b(\text{HxCA}); \text{ or } D^2 = a_1+b_1(\text{HxCA}), \quad \text{(Aldred, 1967)}$$

with correlations for all species above .9,

$$v = b_1+b_2 H\ CA + b_3\ CA \qquad \text{(Bonner, 1975)}$$

$$r = .98$$

and $$v = e^{aH-b} \qquad \text{(Sayn-Wittgenstein, 1969)}$$

correlation not given.

Stand volume tables were used by Larson, et al, (1971). Unfortunately regression functions were not given. Correlations of ground volume per acre estimates to photo volume estimates were .44 to .75 depending on plot size and scale. Correlations of ground of photo estimates of BA/acre ranged from .66 to .80.

Recent attempts at using space photography in forest inventory have been successful only in classifying at the first level. Beyond the forest/non-forest classification, accuracy rapidly decreases (Heller, 1975, Jobin 1974, Kalensky 1975). However, satellite imagery has been useful in the mapping of broad vegetation types and as the first stage of multistage inventories. Computer analyses seems to be the most efficient method of handling this imagery.

Costs and cost functions are often neglected in the reporting of an inventory, but generally cost/area decreases as area inventoried increases and as acceptable variance increases. Costs for inventories based solely on large-scale sampling are about $10 per 1/5 acre plot, and $2 per acre (Standard Error 15%) including costs of flying the photography (Aldred 1967, 1973). One inventory using small scale photography cost $.0063/acre (Standard Error not given) (Cosgriffe, 1973).

5.0 FOREST SURVEY ENHANCEMENT OPPORTUNITIES

Possibilities for enhancements to the Forest Survey may be identified within three broad areas: 1) the sampling framework, 2) sampling methods, and 3) measurement and analysis. Shortly after the meeting of the PNW Forest Survey unit, the University of California group, and Fort Collins resources techniques evaluation personnel, a study plan was prepared by the PNW group to examine four very specific aspects of Forest Survey. The items considered were: 1) the 10 point plot procedure, 2) stratification method and its relation to change variables, and 3) field measurement procedures. In our look at the entire Forest Survey procedure for this study these opportunities will not be excluded from further analysis since they, and others, must be considered as part of the overall sampling framework.

This section serves to identify opportunities with the analysis of these opportunities discussed in section 6.

5.1 The Sampling Framework

The problems of data coordination from several agencies suggest that combining all acquisition activities for forest survey into the Forest survey unit could lead to substantially greater control over quality and completeness of data. In addition data analysis and summary activities could be streamlined so that cost savings in analysis, plus quality control, might offset the added expense of any additional field work that might be required.

Improved quality control could be complemented by defining a minimum complete data set which would provide data needed for national and regional analysis. This data would not be directly oriented towards local level management planning but could still be useful if made available to local managers in either detailed or summary format. In this way data gathered for higher level planning could be used to supplement local level data acquisition activities rather than on local personnel to meet Forest Survey needs. In addition to broader limits on the sampling population and the specific parameters which are to be estimated, there is a need to define the level to which stimates by various population subdivisions are required or desired. Since Forest Survey is regionally and nationally oriented, estimates for these divisions are obviously required. Further, survey activities typically occur in "inventory units" which consist of county groups within states. Finally, the current procedure includes the publication of estimates for specific counties within states. Sampling methods, especially the definition of sampling units, will be affected by these considerations.

5.2 Sampling Methods and Data Sources

A sampling frame as such is not considered in current Survey procedures since sample selection is systematic. If other approaches are considered a sampling framework consistent with the sample unit specification is necessary. Possibilities include a Landsat reference system, the UTM system, the township base of rectangular survey (used by the PNRC study) and the state plane system (used by DNR-GRIDS). The current sampling unit is based on the 10 point plot layout which covers roughly one acre and the complementary TOP plot layout which covers roughly 10 acres. Photo interpretation is based on a pointwise evaluation. Cost reduction could be obtained by considering larger plot sizes which would limit between-plot cost but would increase within-plot cost. Larger cluster plots would also be useful for evaluating treatment or management opportunities. GRIDS uses a 10 acre cell size,

while the PNRC primary sampling units are townships.

Stratification can be used at several levels. At the PSU (Primary Sample Unit) level it must correspond to sample unit boundaries and could relate to either administrative subdivisions based on ownership or land use, for example, or to counties. Alternatively photo interpretation data such as is currently used (volume classes) could be used to stratify in hopes of reducing variability. Unfortunately, it is difficult to achieve a single stratfication which uniformly reduces variability for a number of parameters.

Auxiliary data is required for stratification but can also be used in other ways to increase efficiency. Alternative uses include selection probability definition and ratio or regression estimation. In addition stratification within PSU's is also possible. Remotely sensed data is one source of auxiliary information and could include land use classification derived from satellite or high altitude photography and measurements from large scale sample photography.

Finally, in any sampling system it is desirable to minimize the survey cost while still meeting precision goals. To achieve this, a planning phase is necessary in which background information on the sampling population is used to plan for allocation of effort. Various sources of data, including remote sensing and historical data, can be used to determine what size and allocation of sample units is required. If this planning process does not occur it is likely that more effort than is needed will be expended on the survey. Conversely it is also possible that sample size will be too small to obtain estimates of reasonable precision.

5.3 Measurements and Analysis Procedures

Field procedures and variables measured have already been identified by the survey unit as areas for improvement but they will be considered in this analysis as they interact with other sampling activities. In particular, if any kind of double sampling or ratio/regression technique is used it is important that both auxiliary variables and primary variables are measured on the same physical units.

Update procedures are a necessary activity since Survey activities are cyclical over a period of up to 10 years. Current procedures are based on a stand table projection method. Recent developments in the area of growth and yield modeling might well be incorporated in the update procedure to take advantage of other data as well as potential or actual management activities (Stage, 1973).

Data handling and analysis methods might require updating to account for any changes in sampling methods. Aside from this, there are special handling problems associated with putting data from the other agencies into a form compatible with Forest Survey. Often this necessitates beginning with the basic field data and approximately any items which might be missing or incomplete.

6.0 ANALYSIS OF OPPORTUNITIES

Analysis of opportunities follows the three broad categories identified in Chapter 5: 1) the sampling framework, 2) sampling methods, and 3) measurements and analysis procedure. The relative emphasis on the three, however, varies considerably. The major effort was devoted to considering sampling methods and efficiencies. This is partly a reflection of better data for analysis and partly because there are more and varied opportunities for modifications of current procedures. A secondary effort went to considering the sampling framework. Less data is available for any analysis in this area and the analysis hinges on intangible non-statistical factors rather than statistical considerations. The third category, that of measurements and analysis procedures consists of items that are largely functions of the results of decisions made in the other areas. Discussion of these topics is presented in light of conclusions and recommendations in sampling framework and methods.

6.1 The Sampling Framework

The major problem area identified in section 5.1 relates to the difficulties of integrating data from several agencies or parts of agencies. Other questions have been raised which relate more to the goals and objectives of the survey itself. The alternative to using data gained from other agencies would be for the data to be acquired as an integral part of the Resources Evaluation Unit's activities. The question is: Would that procedure be better?

The cost of acquiring the data as part of the Survey unit's data acquisition activities could be compared with the cost of integrating the data from other sources. Unfortunately, data on cost of activities relating to combining data from other sources is not easily available. Complicating the issue further are the intangible benefits and costs of each procedure.

Taking western Washington as a case-in-point we find that some 2,321,000 acres of commercial forest land are in the National Forest System (NFS). Data for these lands currently is acquired by NFS. The Bureau of Land Management (BLM) is another agency which frequently provides data; however, there is essentially no BLM land in western Washington.

Using the sampling system currently implemented, the number of ground plots for this area would be about 315 and, assuming a photo/ground plot ratio of 1:13, about 4000 photo plots. Using cost figures provided by MacLean (1977) of $180 per field plot and $1.11/photo plot the cost of acquiring the needed data would be about $61,000. Analysis within existing procedures would add to this but not much since no special analysis would be required. This cost must be compared with that of acquiring and analysing the data from NFS. Assuming that a resource analyst and programmer both would be required to integrate this data, and including processing, labor and overhead, the cost of integrating the data analysis could easily approach $30,000.

Cost alone would not appear to be sufficient justification for acquiring the data as part of Forest Survey. There are, however, a number of intangible costs associated with using data from other sources. Primary among these is the fact that little or no quality control is possible from the Survey Unit to insure that all necessary data is collected and that it is collected according to established specifications. If the quality of data is suspect, the overall estimates have a

component of unevaluated error present. If post-acquisition adjustments are made based on some sort of field checking of a sample of plots, additional dollar costs are incurred. If the data is incomplete then special field work is required or approximations to necessary data must be developed. Again there is an unevaluated error component.

Data needs for Survey are likely to be somewhat different than needs of forest managers; hence it is likely that conflict will develop as managers see more clearly their needs and become less interested in providing survey data. Since some data collected as part of Forest Survey may be of use to local managers, cooperative efforts could allow survey personnel to work with the local managers in planning the data acquisition activities. This could lead to reduced data acquisition costs and removal of the need for special analysis efforts.

An additional benefit could be achieved by implementing all data collection efforts within one agency. If all lands were considered part of the sampling population then reserved lands currently excluded from any sampling could be inventoried (perhaps at a less intense level) so that estimates of resource parameters would be available for all lands regardless of their management status. Information on these areas would certainly be useful in providing a more complete picture of the nation's resources.

This whole problem exists within current operational procedures and does not consider any opportunities for cost reductions which might be achieved by implementing other sampling methods.

6.2 Sampling Techniques

Considerable effort was devoted to the analysis of several alternative approaches to sampling for analysis of multiple resources. This included evaluating available data sources, since ultimately an analysis of this type must be tied to a particular population to be sampled. Section 6.2.1 discusses the analysis method including data available for analysis, the rationale for using the Planning Model, an overview of the approach to survey design used by the model, the actual study area selected for analysis, and a summary of the estimation objectives. Finally, the factors to be evaluated are discussed and a section is presented on implementing the model. Section 6.2.2 presents the results obtained and discusses limitations which must be kept in mind for a study of this kind.

It is important to note that the analysis of a small study area, such as the Gray's Harbor site that was actually used, illustrates a planning procedure which could be employed for each unit to be inventoried. Once a basic sampling strategy has been defined the scope of the analysis would be reduced, but this analysis provides the opportunity to take maximum advantage of available prior information in planning the allocation of sampling effort.

6.2.1 Analysis Method

A number of sampling techniques are usually combined in a sample survey, including stratification, clustering, selection probabilities, subsampling and others. The analysis methods, to achieve the objectives of the current study, must address a multivariate (several variable) estimation problem. For that reason univariate procedures are not appropriate. Instead a technique developed at the

University of California (Titus, 1977) has been used.

6.2.1.1 Data Available for Analysis

Two primary sources of data for the western Washington area are available. The first was data previously collected for the Forest Survey under current procedures using a large sample of photo plots for stratification and a smaller sample of field plots. Several possible shortcomings for this data source were identified. First, the time since data acquisition varies up to 10 years. Therefore, changes that have occurred since the data was acquired could be substantial. Second, each photo plot represents slightly more than 1 section of land. A major advantage of this data source is that it conforms largely to the major vegetation parameters of interest for resource assessment.

The second data source was the Washington State Department of Natural Resources. (DNR). DNR has recently been involved with a demonstration project jointly with NASA and the Pacific Northwest Regional Commission (described in Appendix C). The data is based on 1974 acquisition of satellite data and later photo interpretation and field work. In addition, the basic stratification, while not quite of the same type as that currently used by Forest Survey, is much more detailed in its resolution level (approximately one acre per cell). Photo interpretation and field work to measure timber related variables was not of the exact type as Forest Survey; however, it still serves to give good data on basic vegetation characteristics.

It had been hoped that the two sets could be combined since each data source separately has shortcomings which could be reduced in combining them. Unfortunately this was not possible given the limited time in which to complete the analysis. The opportunity to incorporate the Forest Survey data with the DNR data still exists and would be a useful extension of this work.

Cost data has been provided based on a previous study for the Plumas National Forest (Colwell et al, 1974) and for field measurement cost by data provided by MacLean (1977).

6.2.1.2 Rationale for Using the Planning Model

The evaluation process uses a survey planning model developed for multivariate applications where a detailed spatially referenced population representation is available (Colwell and Titus, 1976). A short description of the process and associated set of computer analysis routines, WILLIAM, is included as Appendix J (Titus, 1977).

In order to evaluate the various sampling techniques and methods as they interact in a sampling system, a specific population model must be available from which to derive variance components associated with the different techniques. Satellite data, as summarized in the DNR/PNRC study, fits this need very well since the resolution of the data is roughly one acre. With a land use class assignment for each cell and associated parameter estimates derived from supplementary sources, the model can be manipulated and summarized in a variety of ways. The Forest Survey data has these same properties except that the resolution is only about 600 acres per cell.

Two major modifications to the planning model were made as part of this study. The first was to put the separate analysis components into a single package with a monitor program to control the various components. The result is a more coordinated set of analysis routines which may be executed either separately or in sequence using the monitor function. This will facilitate the transfer of the package to other prospective users. At the same time, however, it must be kept in mind that the WILLIAM package is experimental in nature and even in this study capabilities were added which were not present in the earlier version. For this reason there are components which could be streamlined and made more efficient.

The second modification was addition of an alternative method for stratification using the sampling frame created by the CLUSTER program as input to the ISOCLASS unsupervised classification algorithm. ISOCLASS partitions the population elements into "natural" homogenous groups of sample units. Characteristics used by ISOCLASS for each sample unit are the parameter totals and variance for each of the three parameters to be estimated.

6.2.1.3 The Study Area and Estimation Objectives

A 515,000 acre area adjacent to Gray's Harbor on the central coast of Washington was selected as the study area. Figures 3 and 4 show the physiography and political boundaries in the area. Figure 5 shows a composite image created from the satellite multispectral data used in the analysis, and Figure 6 shows the results of that analysis with eight classes. Figures 7 and 8 show comparable aerial photographs for portions of the Gray's Harbor study area. They may be used for a subjective evaluation of the quality of the composite image (Figure 5) and the classification (Figure 6). For each of the eight classes, data was provided by ESL, Inc, Sunnyvale, California estimating the average DBH, basal area, number of trees, percent crown closure of conifers, percent crown closure of hardwoods, percent crown closure in other categories, and percent crown closure in forest. A mean vector, with a component for each of these seven variables, as well as an associated covariance matrix was provided for each of the eight classes. Appendix K summarizes that data.

From this set of variables three were selected for the estimation objectives in the planning model: basal area, number of trees, and percent crown closure of forest. The first two relate directly to the timber vegetation component and the last relates primarily to the relative amount of timber vegetation. The last variable was included because its variability should be closely related to major changes in vegetation and/or land use.

Figure 3. Gray's Harbor Study Area, Physiography

Figure 4. Gray's Harbor Study Area, Political Boundaries

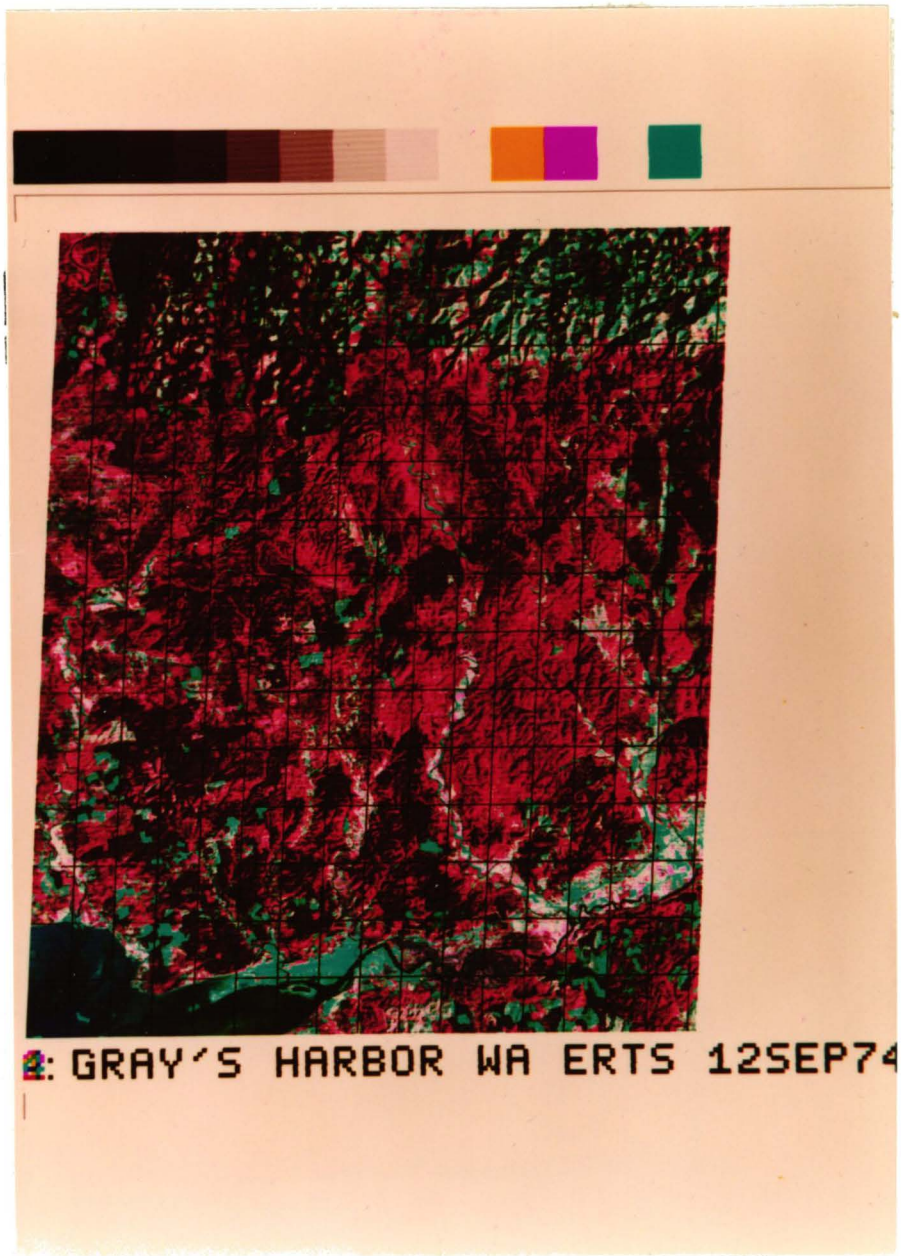
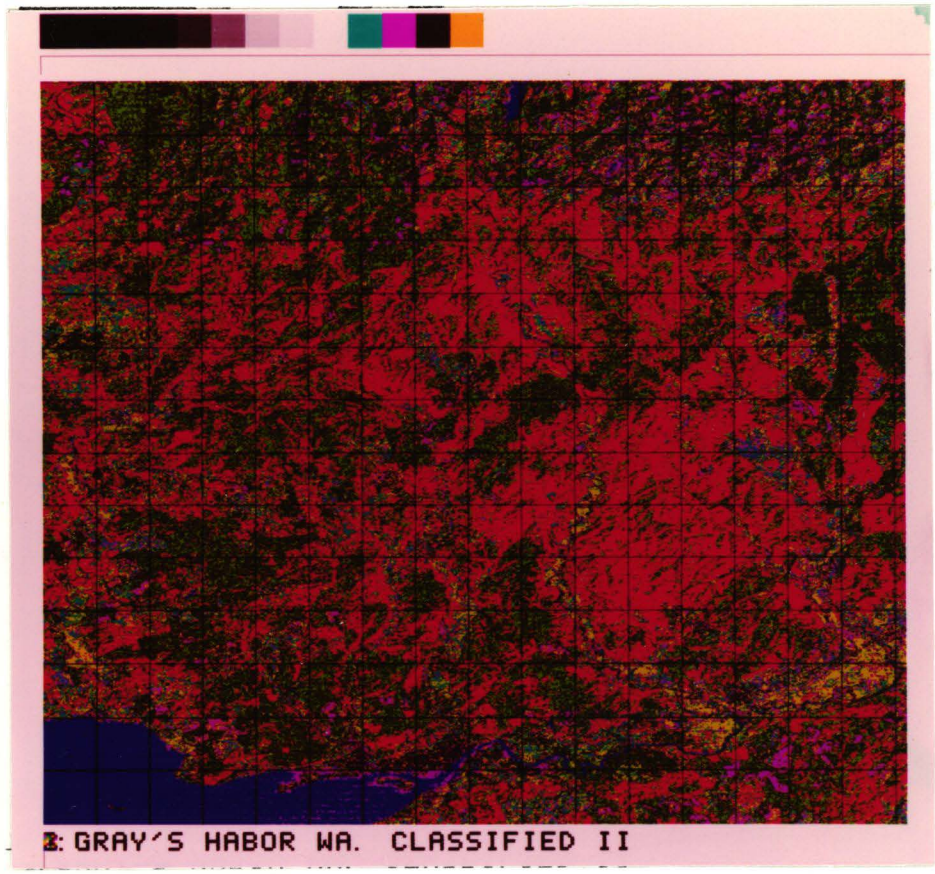


Figure 5. Gray's Harbor, Landsat Composite Image



Code	Color	Interpretation
6	Dark Green	Old Growth
14	Light Green	Second Growth
4	Red	Hardwood/Mix
40	Light Purple	Non Stocked Forest Land
20	Yellow	Non Forest Land
30	Light Blue	Reproduction
1	Black	Fill or not of interest
27	Blue	Water

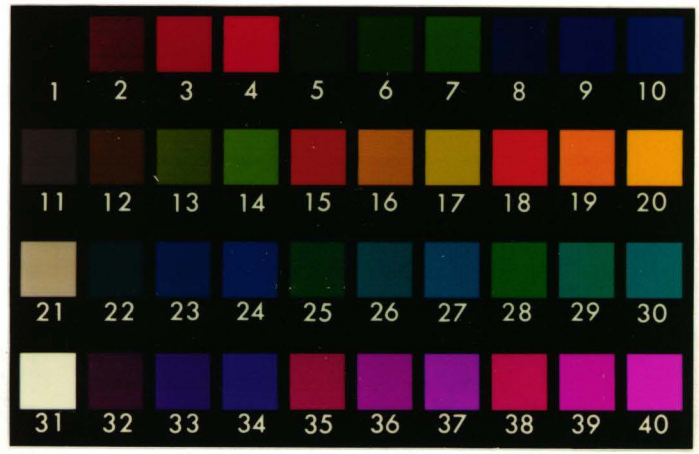


Figure 6. Gray's Harbor Study Area, Classification

Figure 7. 1:60,000 Scale aerial photograph of an area in the vicinity of Block 7 Right and 2 Up on Figure 5.

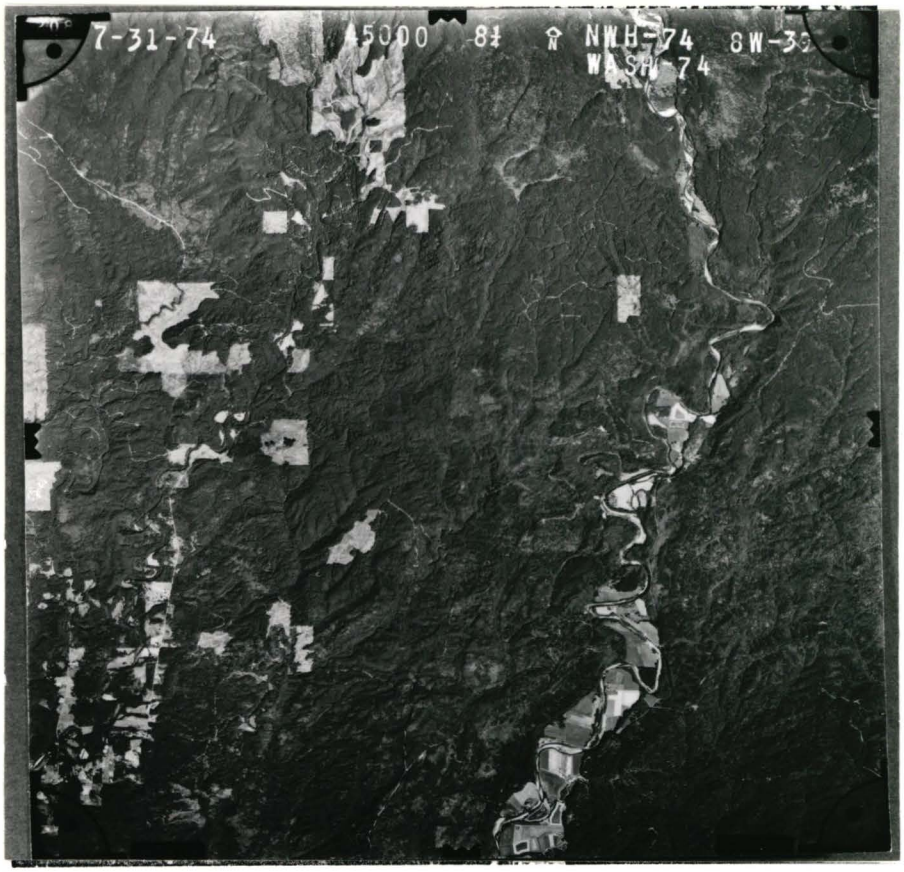


Figure 8. 1:60,000 Scale aerial photograph of an area surrounding Block 10 Right and 8 Up on Figure 5.

The objective in the planning process is to minimize the total variable cost of the survey subject to variance constraints for each of the three parameters to be estimated. Cost functions and data are discussed in section 6.2.1.4. Precision constraints for Forest Survey are given to be ± 10 percent at the one standard error level per billion cubic feet for volume. No other constraints are given except for area. For this reason, and the possibility that precision constraints may change, several values were considered for each parameter.

6.2.1.4 Factors to be Evaluated

Factors which affect the performance of the planning model are of two types: (1) the model parameters used, which include factors fixed at input and not to be determined by the optimization procedure of the model decision process, and (2) the model or decision variables which are factors or values which the model is to fix or identify as being the best, or least costly.

The set of model parameters includes the population means, variances, etc. from which the representation is constructed and the cost information used for fixing the cost of various sampling and measurement activities. In addition the estimation objectives are specified as percentage allowable error precision goals (for example to estimate each parameter within plus or minus five percent of the true value). A probability level for confidence statements is specified, and correlation between auxiliary and primary variables is also required.

For Gray's Harbor, the population data has been described in section 6.2.1.3. The confidence level for probability statements is specified as the one standard error level (67% level of confidence) and the desired precision level as plus or minus ten percent for basal area and twenty percent for number of trees and percent crown closure. Correlation between the auxiliary and primary variables is assumed to be 0.8, a medium range correlation which has been achieved in several prior studies (Aldred, 1967, Colwell et. al., 1974). In addition to these model parameter values, a sensitivity analysis was conducted to show the effects of changes in the allowable error and correlation parameters on the model results. Four different values for correlation were considered (0.8, 0.7, 0.6, 0.5). Three different values for allowable error were evaluated (.05, .05, .05), (.05, .15, .15), and (.10, .20, .20), for basal area, number of trees, and percent crown closure, respectively.

Cost data is taken from two primary sources, MacLean (1977) and Colwell and Titus (1976). The first source provided data on field measurement and travel cost for the projected Forest Service procedures. The second source provided costs for various measurements and sampling activities using remotely sensed data.

Three alternative cost functions are used depending on the type of subsampling used (described in later paragraphs) in the planning process.

$$1)\quad F(\text{STRAT}) = F_1 = \sum_{h=1}^{L}\left(C_{h1}\,\frac{\text{size}}{4}\,n_h^* + C_{h2}\sqrt{n_h^*} \right)$$

$$2)\quad F(\text{STRAT2S}) = F_2 = \sum_{h=1}^{L}\left(C_{h1}\,n_h^* + C_{h2}n_h^*n_h' + C_{h3}\sqrt{n_h^*} \right)$$

$$3)\quad F(\text{STR2SD}) = F_3 = \sum_{h=1}^{L}\left(C_{h1}n_h^* + C_{h2}n_h^*n' + C_{h3}\sqrt{n_h^*} + C_{h4}n_h^*n_n + C_{h5}\sqrt{n_h} \right)$$

Coefficients are interpreted as follows:

F = total variable cost of the subsampling method in parenthesis (see later paragraphs)

C_{h1} = cost of selecting and measuring clusters (PSU)

C_{h2} in F_1 and C_{h3} in F_2 and F_3 = cost of travel between clusters

C_{h2} in F_2 and F_3 = cost of measuring a SSU

C_{h4} = cost of measuring TSU

C_{h5} = cost of travel to TSU

Two approaches to setting the coefficient values were taken. The first assumed that the travel cost for field measurements was a linear function of sample size and the second approach assumed that the function was proportional to the square root of sample size. On that basis the following coefficient values in dollars were used in the analysis:

Cost coefficient set 1	Cost coefficient set 2
C_1 = (70, 1500)	C_1 = (180, 0)
C_2 = (10, 70, 1500)	C_2 = (20, 180, 0)
C_3 = (50, 7, 15, 70, 1500)	C_3 = (50, 7, 15, 180, 0)

The same cost coefficients were used for each stratum. The 180 coefficient for cost set 2, above, represents the average cost for field measurement and travel, using Forest Service techniques. The comparable figures for C_1 in set 1 were determined by considering that 60 percent of the cost is for travel and relating this to a previous inventory using 194 field plots in Gray's Harbor county. Then:

$$C_{2h}\sqrt{194} = (194)(180)(.6)$$

$$C_{2h} \doteq 1500.$$

Decision variables considered in the analysis included:

1. Stratification method - plurality of individual cells (default)

   ISOCLASS

2. Cluster size - 2X2 cells (pixels in the classification map)
   3X3
   4X4
   10X10
   50X25
   65X65/75X75
   75X75

3. Selection probabilities - equal
   proportional-to-size (PPS)

4. Subsampling method - STRAT - stratified, no subsampling

   STRAT2S - stratified, two stage

   STR2SD - stratified, two stage with double sampling within the set of secondary units.

The default stratification procedure takes the stratum for each sample unit (cluster) to be the one with a plurality of individual cells. All cluster sizes were square. The size variable for PPS selection is the number of cells in "good" classes for each cluster. "Good" cells are those within the population to be sampled and in a class of interest; for example, urban and water classes would not be "good" and would lower selection probability while oldgrowth or reproduction classes would be "good".

6.2.1.5 Implementing the Planning Model

A spatial class assignment file was extracted, from the larger set of data scene provided by ESL, Inc., for the Gray's Harbor site. The area consisted of a file

of 700 lines by 810 points as depicted in Figures 5 and 6. Summary statistics for each class were also available from ESL. The SIMULATE program was executed to generate the detailed population representation. Following this, a series of executions of the CLUSTER program summarized the population representation in a form which could be used by the allocation of effort component, SUMT Specific combinations of cluster size, selection probability method, and stratification method defined the particular result file for the CLUSTER component. The SUMT allocation algorithm was then executed for each of the CLUSTER result files. Repeated executions allowed variation of the other model parameters and variables in the analysis. Summaries of results and comparisons among alternatives was completed manually.

Appendix G identifies all data files generated in the analysis as well as the various program components.

Appendix F is a draft user's Manual for the WILLIAM software package.

6.2.2 Results

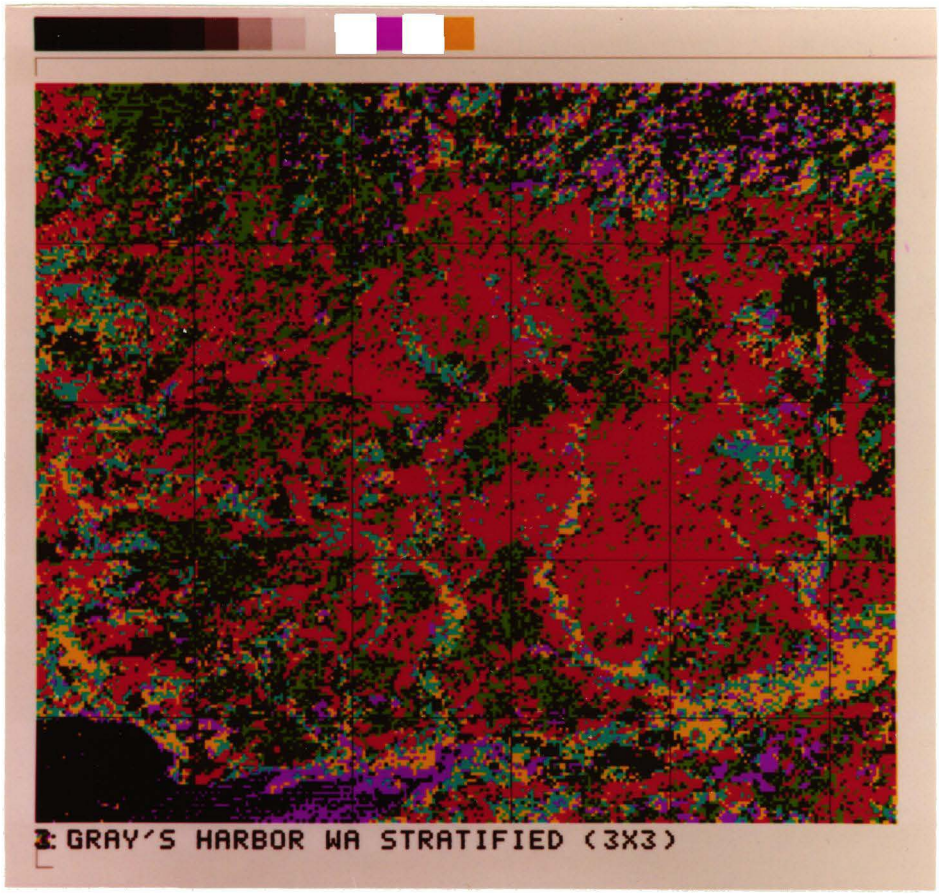
Results for execution of the optimization component, SUMT, are somewhat lengthy. For that reason only a small number of alternatives have been included in Appendix I. Appendix H, however, summarizes the important features and results associated with executions for all model parameters and variables considered for the Gray's Harbor site. In this section, the results are given for the two sets of cost parameters. Following this is a presentation of the sensitivity analysis which resulted from varying the allowable error and degree of correlation between the primary and secondary variables. The final section discusses limitations of an analysis of this kind.

For comparative purposes, three examples of stratification results have been included, two for the default procedure and one using the ISOCLASS procedure. A 3 x 3 cluster size stratification is shown in Figure 9. Figures 10 and 11 show default and ISOCLASS stratifications, each for 10 x 10 cluster size. Color codes in Figure 6, the classification result, and Figures 9 and 10 are comparable. Each of these is based on the 6 classes of interest. Figure 11, however, is based on 13 classes derived by ISOCLASS and they are not directly equivalent to the other figures, at the same time there are similarities in the results. The green colors in Figure 11 are roughly of the same areas as the red classes in Figure 10. The important aspect of each class is not the name given to it, but rather the statistics available to describe the condition likely to be found in that class.

6.2.2.1 Results using Cost Data Set 1

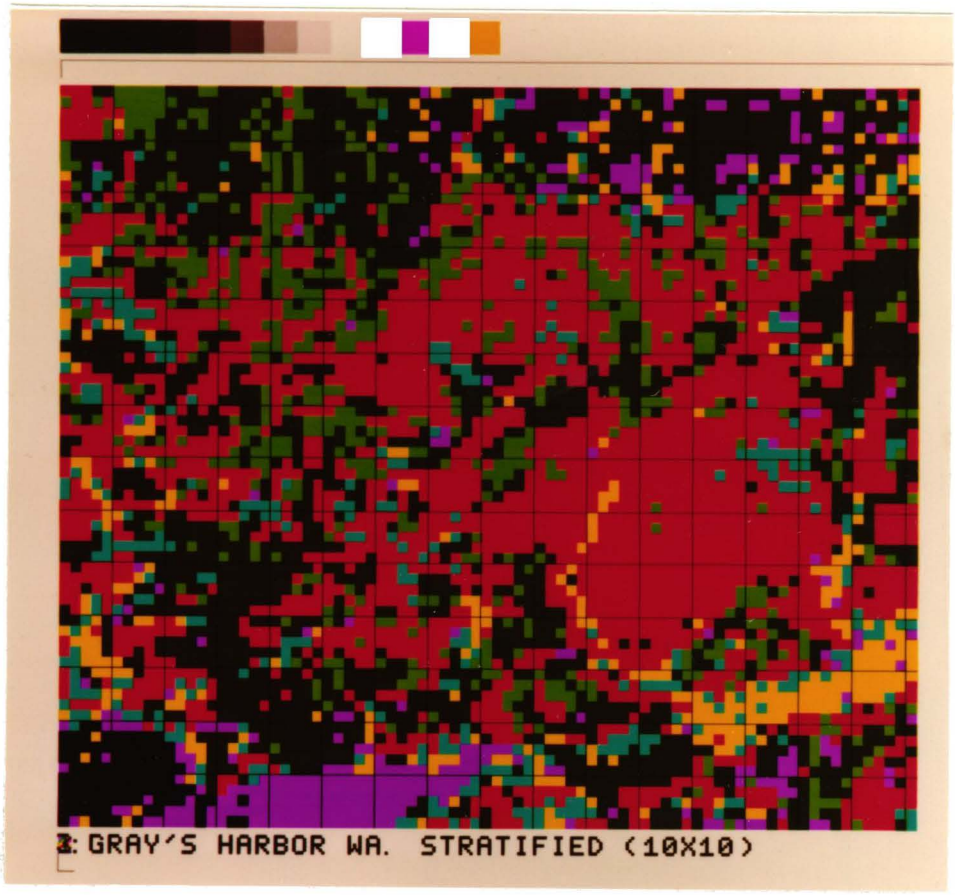
Table 2 summarizes the results using cost data set 1 and allowable error (.10, .20, .20). This allowable error specification approximates the requirements under current Forest Service procedures and the cost data used (set 1) assumes that cost of making field observations is proportional to the square root of sample size.

These results are also given for sampling with selection probabilities proportional-to-size (PPS) and the default stratification procedure. The PPS alternatively consistently yielded a lower cost when compared with equal selection probabilities throughout the study. The ISOCLASS procedure for stratification



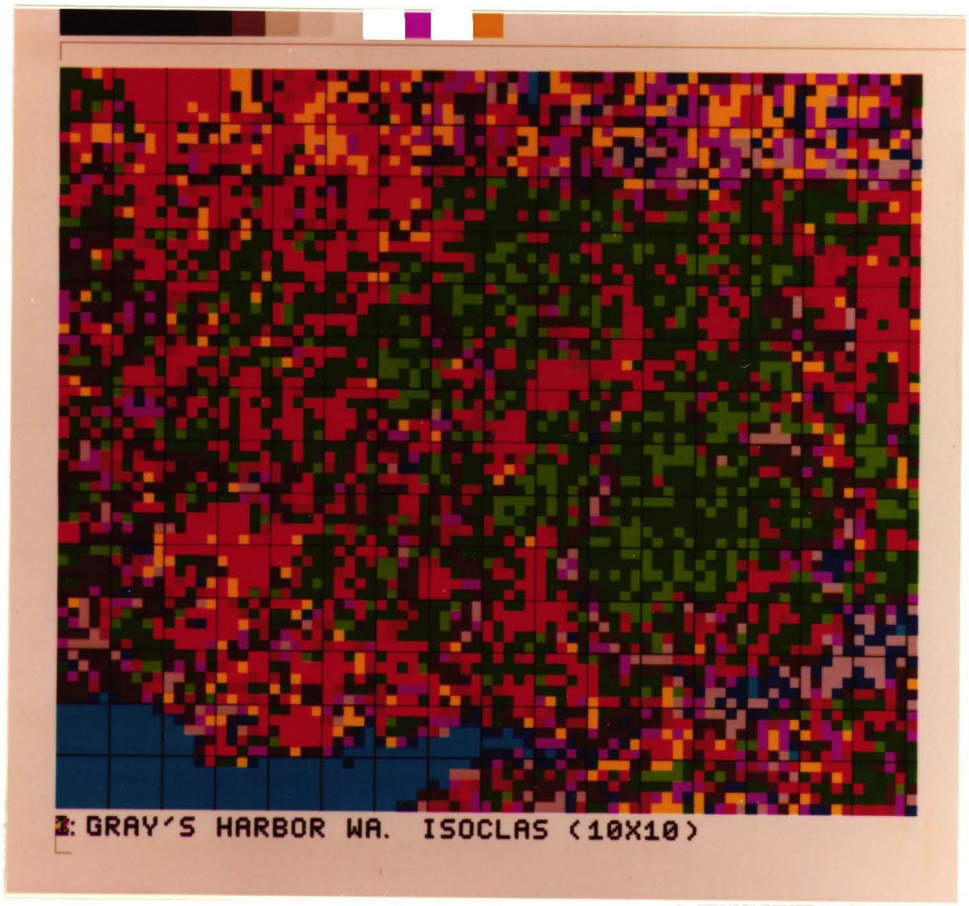
Code	Color	Interpretation
6	Dark Green	Old Growth
14	Light Green	Second Growth
4	Red	Hardwood/Mix
40	Light Purple	Non Stocked Forest Land
20	Yellow	Non Forest Land
30	Light Blue	Reproduction
1	Black	Fill or not of interest
27	Blue	Water

Figure 9. Gray's Harbor, Washington, Stratification (3 x 3 cluster size)



Code	Color	Interpretation
6	Dark Green	Old Growth
14	Light Green	Second Growth
4	Red	Hardwood/Mix
40	Light Purple	Non Stocked Forest Land
20	Yellow	Non Forest Land
30	Light Blue	Reproduction
1	Black	Fill or not of interest
27	Blue	Water

Figure 10. Gray's Harbor, Washington, stratification (10 x 10 cluster size)



Code	Color	Interpretation
6	Dark Green	Stratum 1
14	Light Green	" 2
12	Brown	" 3
11	Gray-Black	" 4
21	Light Gray	" 5
27	Blue	" 6
32	Purple	" 7
4	Red	" 8
25	Green	" 9
36	Light Purple	" 10
15	Orange	" 11
23	Dark Blue	" 12
20	Yellow	" 13

Color chart from Figure 6

Figure 11. Gray's Harbor, Washington, ISOCLASS Stratification (10 x 10 cluster size)

was not consistent in its results (see Appendix H), Time was limiting in work with the ISOCLASS stratification alternative and it is expected that with more experience using this type of data with ISOCLASS should improve the results. For the present, however, the default procedure is recommended because the results were more consistent.

Table 2 presents the results for each of three different subsampling alternatives and seven different cluster sizes. The table entries give the implementation cost in dollars (F) along with the total sample size, summed over strata, for each type of sample unit (n* refers to PSU's, n' to SSU's, and n to TSU's).

If we take the stratified sampling procedure for a cluster size of 2 x 2 (F = $29,672) as the "baseline" procedure which reasonably approximates current Forest Service procedures then we can evaluate the others by comparison with the baseline procedure. While the stratification procedure is certainly not the same as that used by Survey, any differences are offset by the fact that double sampling is not used, and measurements are 4 cells instead of one (less variability) hence the two may reasonably be considered similar.

Comparing the implementation costs, we find that a stratified two stage (STRAT2S) procedure, using 10 x 10 cluster size is 22% less costly than the baseline procedure and that the stratified two stage with double sampling (STR2SD) alternative is 18% less costly, also for 10 x 10 cluster size. It is also evident from the table that increasing cluster size leads to additional reductions in implementation cost. For this reasonably low precision requirement, the stratified two stage alternative performs the best. Differences in cluster size for the STRAT2S alternative are relatively minor, less than 2% reduction as cluster size increases, except for the 75 x 75 size. The 75 x 75 size may be somewhat less typical since for that cluster size there are only about 100 elements in the population. It appears that cluster sizes of 10 x 10 and larger yield about the same cost. The gap in sizes between 4 x 4 and 10 x 10 should be examined further.

It is also interesting to note that for STRAT2S procedure the sample sizes are at the minimum required level (2.0) for each of the six strata (only 5 strata for 75 x 75). The implication of this result might be that under a good ISOCLASS stratification with fewer strata the cost reduction might be even greater.

6.2.2.2. Results using cost data set 2

Table 3 presents results in a format identical to that of Table 2 for cost data set 2. Under this cost data set, travel cost is assumed to be proportional to sample size.

For these conditions we find that the STRAT2S alternative is more costly than the baseline alternative, at all cluster sizes. On the other hand, the STR2SD alternative costs only 1/3 as much for a 10 x 10 cluster size as the baseline and becomes slightly more efficient as cluster size increases.

Table 2. Summary Results of SUMT Executions, Cost data set 1

MODEL PARAMETERS

1.) t = 1.00, α = .67

2.) AE = (.10, .20, .20)

3.) Cost data set 1

4.) ρ = .8

MODEL VARIABLES

1.) Default Stratification

2.) Cluster size -- as shown

3.) Proportional to Size Probabilities

4.) Subsampling procedure -- as shown

	Cost of Survey			Numbers of sample units		
CLUSTER SIZE	STRAT F	STRAT2S F	STR2SD F	STRAT Σn^*	STRAT2S Σn^* $\Sigma n'$	STR2SD Σn^* $\Sigma n'$ Σn
		Dollars				
2x2	29,672			34.1		
3x3	25,658			17.2		
4x4	27,225			12.7		
10x10	96,731	23,072	24,441	12.0	12.0 144.3	25.7 314.5 27.2
25x25		23,343	24,266		12.0 148.2	23.9 310.7 27.3
50x50		23,424	24,129		10.1 149.3	21.9 307.9 27.1
75x75		21,328	21,236		10.1 150.3	21.9 310.5 24.1

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form, A = basal area, B = number of trees
C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table 3. Summary Results of SUMT Executions, Cost data set 2

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$

2.) AE = (.1, .2, .2)

3.) Cost data set 2

4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification

2.) Cluster size -- as shown

3.) Proportional to Size Probabilities

4.) Subsampling procedure -- as shown

	Cost of Survey			Number of sample units		
CLUSTER SIZE	STRAT F	STRAT2S F	STR2SD F	STRAT Σn*	STRAT2S Σn* Σn'	STR2SD Σn* Σn' Σn
2x2	24,437			33.9		
3x3	27,798			17.2		
4x4	36,434			12.7		
10x10	216,007	25,850	8431	12.0	20.5 141.0	24.8 265.0 28.6
25x25		26,371	8437		22.1 144.0	24.4 263.8 28.4
50x50		26,645	8286		21.5 145.6	23.6 263.5 28.3
75x75		26,732	7671		19.8 146.3	22.1 166.0 25.3

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form, A = basal area, B = number of trees
C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

6.2.2.3 Sensitivity of the Model solution to changes in Allowable Error

Table 4 summarizes, for a particular set of model parameters and variables, the percentage changes in implementation cost for three different levels of allowable error. Results are given for both approaches to setting the travel cost coefficient. The greatest percentage increase occurs with cost data set 2 -- more than twice that associated with cost data set 1. Similar trends may be observed in other executions of the model found in Appendix H.

It is also important to note that in one case the allowable error is only changed for the second and third parameter, number of trees and percent crown closure of forest. This change, from ± 15 percent to ± 5 percent causes a substantial increase in implementation cost (F) and shows that at least one of these parameters is considerably more variable than basal area which has an allowable error of ± 5 percent in both cases.

6.2.2.4 Sensitivity to Correlation

Correlation between primary and auxiliary variables is important only for the double sampling, STR2SD, alternative. For most of the analysis a correlation of 0.8 was assumed for each of the three parameters to be estimated. To evaluate the effect of poorer correlations on the implementation cost, four separate executions were made using the correlations to 0.8, 0.7, 0.6, and 0.5. Table 5 summarizes the results of the decreasing correlation from 0.8 to 0.5 resulted in only increasing the cost by about 20 percent. Since the parameters for this analysis are the same as those in Table 2 it is possible to compare the results with the baseline (STRAT) alternative. Even with the correlation as low as 0.5 (25% of the variability accounted for) the STR2SD alternative (F = $27,140) is still 8.5 percent lower in cost than the baseline alternative (F = $29,672). On this basis the correlation, which may seem poor by the usual standard, still provides valuable information in the sampling system.

6.2.2.5 Limitation of the Analysis

A number of limitations to this analysis of alternative sampling schemes must be mentioned. The whole analysis rests on the hypothesis that the population representation generated is a reasonable approximation to the real world population to be sampled. This hypothesis cannot be reasonably tested because if the data were available then the need for sampling would be eliminated. To obtain the necessary data would require an effort of the very kind we are trying to design, and even then a sample would not guarantee a valid comparison.

The parameter statistics made available by ESL Inc., to accompany the class assignment map area based upon photo interpretation data without any field data. This was necessary because of the delivery time required for the data to be used in our analysis.

The ISOCLASS stratification procedure was incorporated into the model as a new option and substantially more time than originally planned was expended in implementing the procedures. Because of this there was insufficient time to fully develop and evaluate the ISOCLASS analysis procedure for Gray's Harbor. Additional work to evaluate the control and performance of ISOCLASS for this type of application would be very desirable.

Table 4. Sensitivity of the model solution to changes in allowable error.

MODEL PARAMETERS

1) Probability level for confidence statements, t = 1.00, $\alpha \doteq .67$
2) Precision constraints - Variable as shown
3) Cost coefficient data set 1 C = (50, 7, 15, 70, 1500)
   2 C = (50, 7, 15, 180, 0)
4) Correlation $\rho = 0.8$

MODEL VARIABLES

1) Stratification method - Default
2) Cluster size, X = 10, Y = 10
3) Selection probability - proportional to size
4) Subsampling procedure - Two stage with double sampling

Cost Coefficient Set 1

Percent Change in F	Allowable Error	Cost F	Σn^*	$\Sigma n'$	Σn
+ 199.45	(.05 .05 .05)	73,188	105.2	3513.9	102.1
+ 21.05	(.05 .15 .15)	29,586	35.7	534.3	35.7
0	(.10 .20 .20)	24,441	25.7	314.5	27.2

Cost Coefficient Set 2

Percent Change in F	Allowable Error	Cost F	Σn^*	$\Sigma n'$	Σn
+ 482.73	(.05 .05 .05)	49,130	108.8	3389.1	108.9
+ 42.63	(.05 .15 .15)	12,025	36.7	458.9	37.6
0	(.10 .20 .20)	8,431	24.8	265.0	28.6

Table 5. Sensitivity of the model solution to changes in the correlation parameter

MODEL PARAMETERS

1) Probability level for confidence statements, $t = 100\,\alpha \doteq .67$
2) Precision constraints AE = (.10, .20, .20)
3) Cost coefficients data set 1 C = (50, 7, 15, 70, 1500)
   2 C = (50, 7, 15, 180, 0)
4) Correlation -- as below

MODEL VARIABLES (specified for a single run of SUMT)

1) Stratification method -- Default
2) Cluster size, X = 10, Y = 10
3) Selection probability -- proportional to size
4) Subsampling procedure -- Two stage with double sampling

Cost Coefficient Set 1

Percent Change in F	Correlation	Cost F	Sample Sizes Σn*	Σn'	Σn
+ 11.04	.5	27,140	31.9	345.3	33.2
+ 8.35	.6	26,483	30.4	338.9	31.6
+ 4.81	.7	25,616	28.5	329.4	29.7
0	.8	24,441	25.8	314.5	27.2

Cost Coefficient Set 2

Percent Change in F	Correlation	Cost F	Σn*	Σn'	Σn
+19.45	.5	10,071	31.8	292.3	34.6
+14.66	.6	9,667	30.1	286.4	33.1
+ 8.39	.7	9,138	27.8	277.9	31.2
0	.8	8,431	24.8	265.0	28.6

6.3 Measurements and Analysis Procedures

Measurement procedures were only considered to insure that they were not incompatible with the alternatives considered in the planning model analysis. The field procedure would not necessarily need to be changed under two stage sampling. However, under the two stage with double sampling method it becomes essential that both primary and auxiliary measurements are made on the same physical units. If this alternative were to be implemented, field procedures would need to be reevaluated. In addition, if two stage sampling is considered it would be desirable as well to consider whether alternative measurement procedures could be used, for example, to identify treatment opportunities over the whole sample unit using available aerial photographs in conjunction with the field work required for direct measurements.

7.0 RECOMMENDATIONS

A major assumption, made in section 1.2, that the orientation of assessment surveys should be regional and national rather than local is important since many recommendations are a result of this assumption. This is not to imply, however, that subregional summaries are not possible, but rather that they should be a distinctly minor consideration in producing information products as a result of the survey activities. Recommendations are discussed in the sequence of earlier sections, relating to (1) the sampling framework, (2) sampling methods, and (3) measurement procedures.

7.1 The Sampling Framework

Recommendation 1. Reliance on other agencies for data to be incorporated in estimates of resource parameters should be minimized. While not justified by cost considerations above, reduced reliance on others for data allows greater control over the quality, timeliness, and completeness of data required for resource assessments. Data from other agencies may well be used for planning and design efforts and even as auxiliary information to be used in the sampling system. However, the survey system should always rely on final direct measurements under the control of the Assessment Unit.

Recommendation 2. A formal planning mechanism should be implemented, by the Assessment Unit, to take better advantage of the information accumulated through repeated surveys. The importance of this activity, and of adapting a formal analysis mechanism cannot be overemphasized. Data and information accumulated by the Assessment Unit, as well as other agencies, can be used to significant advantage in developing a data structure which over time can lead to better approximations of real population conditions. This data structure can then be used in a planning system, such as that implemented for Gray's Harbor, as well as in the survey system itself. Results of the analysis for Gray's Harbor indicates, for example, that while about 85 field plots were taken for the study area, only about 35 were required according to the planning model.

Recommendation 3. All land, regardless of management or political status, should be included in the population to be sampled. As the need for multiple resource assessment increases, assessments should be capable of providing information on all resource components regardless of their management status. For this reason National Parks and other reserved lands should be evaluated, even if at a reduced level of effort.

7.2 Sampling Methods

Recommendation 4. The stratification should be maintained and updated over time rather than starting over at each new inventory. If a population model is developed and maintained over time, the stratification may be derived directly without a costly new effort at each new inventory. Also, the sampling error associated with estimates of change will be reduced.

Recommendation 5. Currently Forest Service procedures use a small 10 point cluster sample unit. Larger cluster sample units, on the order of several hundred acres, could be used in conjunction with two stage sampling to reduce total survey cost and permit evaluation of treatment and management opportunities as they occur within, and are affected by, surrounding vegetation and land use patterns. Additional improvements may, under certain circumstances, be made by including double sampling within the second stage units so that additional remote sensing data could be incorporated. Results of this analysis indicate that cluster sizes above 10 x 10 are relatively equal in cost, other factors equal.

Conditions under which double sampling would provide a reduction in cost depend on the cost function and allowable error. Small allowable errors generally favor the double sampling alternative. The linear travel cost assumption shows that for an allowable error as given in Table 2 (.10, .20, .20) the double sampling alternative (STR2SD) is not significantly better. In fact, for 10 x 10 cluster sizes it is actually higher.

Recommendation 6. Since primary sample units (PSU) are likely to vary in size from one sample unit to another, a proportional-to-size sample selection scheme using size of PSU will further reduce cost. This conclusion was found true in the earlier study for the Quincy Ranger District study (Colwell and Titus, 1976) and was further substantiated for Gray's Harbor in the present study.

7.3 Measurements and Analysis Methods.

Recommendation 7. Measurements and field procedures for individual plots will not be significantly affected unless, or until, double sampling procedures are considered. In two stage sampling the units are measured directly at the second stage. For double sampling measurements of auxiliary and primary variables must both be of the same physical unit.

8.0 THE FUTURE

While a number of specific recommendations have been made based on the study of Gray's Harbor, there are a number of problems not examined because of time limitations. In addition there is the important topic of implementing recommendations the Forest Service feels are most promising. This section discusses these issues as well as the larger problem of data management and its relationship to sample surveys.

8.1 Implementation of Recommendations

Carrying out all data acquisition activities and enlarging the population to be sampled will require restructuring and perhaps increasing the size of the field data collection effort. There are, however, several possibilities for working cooperatively with agencies which might benefit from some of the data derived. As long as the measurement activity is directed and supervised by Assessment Unit personnel it would be reasonable, and even helpful to have someone from the local agency assist in the measurement of field plots. By this means labor cost, and perhaps travel time, could be reduced.

Implementation of a planning system, or model, such as that used for Gray's Harbor will require training of personnel in the use of new techniques for evaluating sampling alternatives. A complementary effort is also required to insure availability of data on prior forest conditions.

Alternative sampling schemes will require modification of analysis procedures. Measurent procedures will not be significantly affected unless, or until, double sampling is considered.

8.2 Research Needs

The initial hypothesis, on which the planning results are based, is that the population representation derived from the multispectral classification and associated statistics is a "reasonable" model of the real world. An evaluation of this representation would be desirable to determine whether or not the population model is a reasonable reflection of the real-world population. Such a comparison would be difficult and wound not yield conclusive results, but it would provide some evaluation of the initial hypothesis. Alternatively, it would be desirable to incorporate data from other sources into the population model. A prime source is the data available from previous Forest Service inventories, including both field data and photo interpretations of land use.

Certain aspects of the planning model, WILLIAM, require further research and development. Use of the ISOCLASS stratification procedure requires more experience in determining appropriate parameter values to control the clustering process. Certain additional capabilities in the planning model would be desirable, particularly subsampling alternatives. Each new application of the model identifies components or aspects peculiar to the new application and these may imply potential refinements or improvements.

If the double sampling option for subsampling is considered, a study of large scale photo measurements, for a variety of scales, in light of the primary variables of interest should be considered. Updated photo yield tables could be developed as a part of such a study. It is also possible that some variables might only need to be measured on photos. Additionally, a look at field plot definition and measurement, in light of new sampling methods, should be undertaken to complement photo measurements analysis.

Finally, the potential for longer term research and development of the planning process itself must not be overlooked. The Gray's Harbor site provides a unique opportunity for incorporating additional data sources in the population model. If used in a longer term context the study area should be modified to follow survey unit boundaries rather than the arbitrary limits used in this study.

8.3 The Data Management Problem

Throughout the project a single factor, data and its availability, has been very important in allowing flexible analysis of alternative sampling procedures. Currently massive amounts of data are available and additional data is being collected every day. An effective management system to integrate update, and maintain data for the population of interest would allow flexibility in planning as well as implementation of sample surveys. Beyond that, there are additional possibilities for using data for general resource management problems.

A data base for geographic wildland population is by nature dynamic and continually changing. This model of the physical system has, therefore, the potential to be continually improved; associated with these improvements is a corresponding opportunity for improved analysis and design of sample surveys to provide special items of information which are needed for resource management decisions. Tremendous opportunities for development exist if a research and development project is maintained for one or several study areas on a continuing basis for study of procedures for developing and maintaining the data structure. Complementary development efforts can then consider planning and implementation techniques for sample surveys and other uses to which the data might be put.

A long term commitment is needed both on the part of the research group and the Forest Service to insure that the developmental effort is parallel to operational needs of the agency. In this way transfer of new developments from a research to an operational context would be facilitated. Taking Gray's Harbor as a current example, the data structures which began as a remote sensing study would be enlarged to include other sources of information useful in characterizing the resource. Such information included ownership, topographic, and other biological and physical factors as well as cultural features such as transportation systems, recreational factors and production centers. With this kind of a data structure developed and maintained, planning and design of future surveys can be made in a much more meaningful context.

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APPENDICES

A. Study Plan
B. Forest Survey Implementation Summary, R-6
C. PNRC Remote Sensing Study Summary
D. Table 6.1 extracted from BLM-Susanville project final report
E. Annotated Bibliography
F. Draft WILLIAM User's Manual
G. LBL File structure for WILLIAM Program and test site data
H. Summary of WILLIAM Results for the Gray's Harbor test site
I. Selected Results from execution of the SUMT Component of the WILLIAM package for the Gray's Harbor test site.
J. Use of Multispectral Data in Design of Forest Sample Surveys
K. Gray's Harbor class statistics provided by ESL.

APPENDIX A

STUDY PLAN

OBJECTIVES

1) To develop specifications, design summaries, and estimated tradeoffs for various enhancements to the current Forest Survey inventory procedures. Enhancements considered will include both sampling and measurement techniques and multiresource variables of interest in the broader context of RPA.

2) To begin development of a broadly-based data structure and inventory system to meet the broader informational needs implied by the RPA. Initial work will deal with the construction of a data base which will be necessary for implementing a modelling approach to evaluating sampling alternatives.

3) To assist in implementing plans and procedures which may be incorporated in the Forest Survey. Enhancement to the current Forest Survey procedures could include both remote sensing techniques and modifications in ground measurement procedures. Recommendations will be included for possible extension of designs to a South Carolina test site.

TASK I: Informational Needs and Institutional Constraints

Subtask I.1. In consultation with Forest Service personnel identify as many of the informational needs of the Forest Service as are required to meet the objectives of this study.

Subtask I.2. Identify the institutional constrants within which the Forest Survey must operate and those which may affect the way in which information production efforts are conducted to meet the needs of RPA.

Task II: Forest Survey Enhancements

Subtask II.1. Review recent literature and current studies dealing with applications of remote sensing to inventory of natural resources. Prepare annotated bibliography showing pertinent conclusions, variables utilized, correlations between photo and ground variables, cost figures, etc. Prepare the material in a suitable format for possible joint publication with USFS.

Subtask II.2. Review, in depth, current Forest Survey procedures for the western Washington site, including measurements, sampling, and variables evaluated. The South Carolina site will be evaluated but not with the same emphasis as the Washington site. Prepare a detailed summary description of each component of the current Forest Survey system. This summary will be used in II.4 to aid in identifying and evaluating opportunities for enhancement

Subtask II.3. Review and summarize information gathering activities of other agencies concerned with the western Washington site, particularly Washington State Department of Natural Resources and the Pacific Northwest Regional Commission to determine what could be included in the data base for the western Washington inventory.

Subtask II.4. Integrate the findings in subtasks 1-3 and identify possible survey enhancements in the following areas:

1. Sampling units (size, shape, type)
2. Stratification
3. Auxiliary data, sources and uses
4. Measurements, procedures and variables evaluated
5. Data handling and analysis
6. Update procedures and data sources
7. Design for allocation of effort

Subtask II.5. Prioritize enhancement opportunities by cost and summarize design and operational modifications necessary to implement them. Provide assistance in implementing any procedure which might be incorporated into the Forest Survey. Primary emphasis on recommendations will be the Washington site with a lesser effort for South Carolina.

TASK III. Longer term design of a system to meet RPA informational needs.

1. Prepare a plan for implementing a multivariate planning and design model (of the type developed under the NASA-FAP project) to evaluate allocation of effort and cost for a variety of alternative sampling systems which might be appropriate in the RPA context. With the need for data over large areas and for multiple parameters, an appropriate data base is a prerequisite for a model of this type. For this reason the plan would address the requirements, availability, and, if necessary, development of such a data base. The use, evolution, and update of such a data base over time would be considered as it relates to design for special purpose or periodic inventories.

PROJECT SCHEDULE

Task	Subtask	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
I	1- 2-	effectively completed								
II	1	———	———	———	———	- - -	- - -	- - -	- - -	- - -
	2	———	———	———						
	3	———	———	———						
	4			———	———					
	5				———	———	———	- - -	- - -	
III								———	———	———

——— primary effort

- - - - - - - - secondary effort

APPENDIX B

Forest Survey Implementation Summary, Pacific Northwest Survey Unit
Western Washington Inventory

1. Origin and evaluation of forest survey
2. The management context
3. Estimation objectives
   - .1 population specification
   - .2 parameter specification
   - .3 desired format for summarizing estimates
4. Sampling system description
   - .1 sampling model: population, sampling units, sampling frame
   - .2 parameters
   - .3 auxiliary data: population subdivisions and related variables
   - .4 sampling technique and estimators
   - .5 sample size and allocation
5. Implementation procedures and specifications
   - .1 sample selection
   - .2 measurements
   - .3 data recording
6. Analysis procedures
   - .1 summary of estimators
   - .2 analysis techniques

1.0 Origin and evaluation of Forest Survey

1.1 originally authorized by McSweeney-McNary Act of 1928

1.2 modified and expanded over time most recently affected by the Renewable Resources Planning Act of 1974

2.0 The Management Context

1.1 The survey provides information used primarily for natural resources assessment.

1.2 Regional and subregional data is also provided for assessments at these levels.

3.0 Estimation Objectives

3.1 Population specification is based largely on statements of the kinds of lands which are not included in Forest Survey unit activities. However, some areas which are not included in Survey data acquisition activities are included for estimations by using data acquired by the other agency. Specifically:

1) NFS lands excluded (data from NFS inventories is used)
2) BLM lands excluded (data from BLM inventories is used)
3) Private range lands are excluded
4) Reserved lands like national parks and state parks are excluded.

3.2 Parameters for timber resources are defined in an extensive set of tables in the FS Handbook on Forest Survey. Basically they relate to volume, areas, growth, removals and mortality. As of this point in time other parameters relating to disciplines like range, recreation, and water are not included.

3.3 The format for presenting the timber estimates is specified in the Forest Survey Handbook

4.0 Sampling System Description

The sampling procedure is described as "double sampling for stratification". Area estimates are based on the large sample of photo plots, and specific measurements of parameters are made by a smaller sample of plots in the field. For Western Washington the NFS is the only primary source of other data which is used in generating estimates. The use of this data removes the need for approximately 315 field plots and 4000 photo plots which would have to be evaluated if Survey were to handle data acquisition themselves under the current system.

4.1 Sampling Model

- population as described in 3.1
- sampling units are based on the established 10 point cluster procedure covering about 1 acre and simultaneously a new 10 point cluster which covers about 10 acres.
- no sampling frame as such is constructed since plots are selected on a systematic basis.

4.2 Parameters

- timber, as described in 3.2
- range land is not significant in Western Washington
- no other parameters are included for estimation
- areas are estimated for ownership classes, stand size, site and species class.

4.3 Auxiliary data

- population subdivision data is interpreted from photos or other sources to obtain
    1) ownership class
    2) land use class
    3) counting and inventory unit
- related variables are evaluated on photos to aid in the stratification into land use including

1) a photo volume estimate based on interpretation of stand height and percent crown cover for use with photo volume tables.

2) treatment opportunity and "alternative cut" classes are interpreted

- elevation, precipitation and topography are recorded as well.

4.4 Sampling techniques and estimators

- stratification is into land use classes and for forest land into volume classes as follows:

0 - 2000 cubic feet/acre
2001 - 4000
4001 - 7000
7001 +

- selection probability and methods are not evaluated since selection is systematic
- the statistical model is the usual double sampling for stratification procedure as described by Cochran (1963). This model however, does not, strictly speaking, fit the system since sampling is systematic and field plots are selected independently of the stratification (see section 4.5).

4.5 Sample size and allocation

Based on the systematic 3.4 mile grid for field plots, approximately 22 field plots are required per 15' quad sheet. Supplementing this are approximately 300 (216-345) photo plots quad sheet. These plots are located systematically but not on a square grid basis.

The large systematic sample of photo plots is used to obtain area estimates and stratification. However, the selection and location of field plots is by the 3.4 mile grid which is effectively independent of the stratification of photo plots. Allocation of field plots among strata is, therefore, by post-stratification. The effect is nearly proportional-to-area allocation, but this procedure really represents

a compromise of the purpose of stratification. This problem is implicitly referred to by the 1976 Photo Interpretation manual on page 29 in the "Photo Interpretation Point Summary" section.

5.0 Implementation procedures and specifications

Physical procedures for selecting the sample units, making measurements and recording data are covered in considerable depth by the field procedures and photo interpretation manuals.

6.0 Analysis procedures

This portion of Forest Survey procedures is not well documented. Portions of several computer packages are used including the TRAS system for inventory update, and the Northeastern Forest-Inventory data processing system. In addition special analysis is required for data obtained from the NFS. Output formats are well documented by the Forest Survey Handbook and the recent Resource Summary publications.

APPENDIX C

PNRC Western Washington Inventory Implementation Summary

1. Origin of the PNRC Study
2. The management context
3. Estimation objectives
   - .1 population specification
   - .2 parameter specification
   - .3 desired format for summarizing estimates
4. Sampling system description
   - .1 sampling model: population, sampling units, sampling frame
   - .2 parameters
   - .3 auxiliary data: population subdivisions and related variables
   - .4 sampling technique and estimators
   - .5 sample size and allocation
5. Implementation procedures and specifications
   - .1 sample selection
   - .2 measurements
   - .3 data recording
6. Analysis procedures
   - .1 summary of estimators
   - .2 analysis techniques

1.0 Origin of the PNRC Study

The state of Washington, DNR, working with the Pacific Northwest Regional Commission (PNRC), ESL Incorporated, and the NASA Ames Research Center have undertaken a project to inventory the forest resources of Western Washington as a demonstration of the use of multistage sampling as a means of integrating ground, aircraft, and satellite remotely sensed data to estimate timber parameters.

2.0 The Management Context

The PNRC is involved with regional planning and development and is a primary user of the data to be generated by this on-going study.

3.0 Estimation Objectives

3.1 Population Specification

Commercial forest land within a 38 county area comprises the population.

3.2 Parameter Specification

Average basal area per acre is the primary parameter of interest. Estimates are required for each of 5 major ownership categories and for several general stand categories as follows:

Ownership	Stand Category
USFS	Douglas-fir
other federal	Western Hemlock
State	reproduction
large private	old growth
small private	hardwoods

Additional parameters are to be estimated including

1) net volume
2) acreage
3) stems per acre

by area and site class except for old growth stands

3.3 Desired Format for Summarizing Estimates

1) Tabular summary of estimates
2) Computer digital data resulting from the computer analysis of digital satellite
3) Color coded maps of digital analysis results
4) Documentation of techniques

4.0 Sampling System Description

4.1 Sampling Model

Population-Western Washington

Sampling units - townships for PSU's

Sampling frame - Township list
Stratification by ownership desired but could not be implemented because of time constraints

4.2 Parameters - Basal Area by Ownership (primary)

Precision objective ± 10 percent at α = .05 for BA/acre by ownership
Other parameters added as secondary interest related to timber

4.3 Auxiliary Data

1) Satellite data for land use/vegetation classes
2) Photo interpretation data included:
   - forest type or land use class
   - % crown closure ~~and~~ By species groups
   - height classes for stand Overstory
   - average crown diameter
   - slope, aspect, position

4.4 Sampling Technique

1) Stratification 5 ownership strata
   USFS
   Federal other
   State
   large private
   small private

also DF and W. Hemlock estimates, old growth, young growth, Hardwood stands.

2) Selection probability - PPS "proportional to estimated acreage of stocked forest land" (p. 22)

But the description of selection procedure sounds like 50 PSU were allocated independently of the reported stratification, see D, p. 22.

3) Statistical model - two stage with double sampling.

4.5 Sample Size and Allocation

1) 50 PSU's were allocated at random independently of stratification.
2) 60 SSU's were sampled within each PSU in proportion to the stand types within the unit. Plot location was based on random selection of coordinate values.
3) From the set of SSU's 29 old growth and 49 second growth and hardwood plots were selected for field measurement.

5.0 Implementation Procedures and Specifications

5.1 Sample selection is according to established procedures for PPS and random sampling

5.2 Measurements

- computer analysis is based on both unsupervised and maximum liklihood discriminant analysis procedure
- photo interpretation was made on several different scales of imagery. depending on availability
- ground data collection was by skilled workers from DNR with 10 percent inspected by supervisors

5.3 Data recording - forms not available

6.0 Analysis Procedures

Still on-going, documentation is not available.

BUREAU OF LAND MANAGEMENT

RESOURCE INFORMATION REQUIREMENTS

Information Desired	Desirability	Use/1	Available Data
RANGE RESOURCE NEEDS:			
1. range vegetation types	HIGH	URA/MFP	Range surveys; require greater accuracy
a. broad			
b. community			
2. range condition		URA	None for 90% of District
a. range type			
b. planning unit			
3. range trend		URA	None for 90% of District
4. forage production		URA	Data not current on 90% of District
a. by range type			
b. estimate for planning unit			
5. ground cover class	HIGH	URA/MFP	old data; needs updating
6. forage utilization		URA	
a. shrubs	HIGH		
b. grasses	HIGH		
c. forbs	LOW		
7. meadow location	HIGH	URA	not available for sites less than 10 acres
8. areas suitable for treatment	HIGH	URA/MFP	
9. fenceline location	LOW	URA	

/1 Unit Resource Analysis (URA); Management Framework Plan (MFP); Analysis Planning (AP)

• Assessment or judgement by UC personnel; all others by BLM resource specialists.

DATA SOURCE FOR INFORMATION

	Analysis Mode: Manual(M); Discriminant Analysis(DA); Multistage Approach(MA)							
ERTS	Small Scale/1	Medium Scale/2	Conventional/3	Others/4	Ground Sampling	Thermal Infrared	Radar	Frequency of Data Collection
a. DA*	M				X			5 to 10 years
b. DA*		M			X			
a. DA*					TRANSECT/ Photo plot			5 years
b. MS*		MS/M*		LSC				
				VLSC	Line trans.			5 years
								5 years
				VLSC	X			5 years
b. MS*		MS*		LSC*	veg.species & % cover			
				VLSC	X			5 years
				VLSC	X.			5 years
					X			
					X			
					X			
DA*	M*	M						
	M	M			X			
			M					

/1 1:120,000 scale color-infrared highflight aerial photography, positive trans.,9 x 9"format.
/2 1:30,000 scale color-infrared highflight aerial photography, positive trans., 9 x18"format.
/3 1:15,840 scale black-and-white aerial photography, print, 9 x 9" format.
/4 Large-scale color aerial photography 1:1000 scale and smaller(LSC); very large scale, aerial photography, 1:1000 scale and larger (VLSC).

Table 6.1 Matrix of informational requirements and the remote sensing data types which can be utilized to satisfy the inventory needs of BLM resource specialists.

BUREAU OF LAND MANAGEMENT

RESOURCE INFORMATION REQUIREMENTS

DATA SOURCE FOR INFORMATION

Information Desired	Desirability	Use/1	Available Data	Analysis Mode: Manual(M); Discriminant Analysis(DA); Multistage Approach(MA)								
				ERTS	Small Scale/1	Medium Scale/2	Conventional/3	Others/4	Ground Sampling	Thermal Infrared	Radar	Frequency of Data Collection
FOREST RESOURCE NEEDS:												
1. basic inventory data	HIGH	AP	not current									10 years
a. forest cover type (broad)		URA	" "	a. DA*	M*	M*			X			
b. forest cover type (specific)		MFP	" "	b.	M	M		1:12,000sc. color & CIR				
c. timber volume:		URA/MFP	" "									10 years
1) cover type							M					
2) age class								" "	X			
3) regional estimate				c. MS*		MS		LSC*	X			
d. stand age and site		URA	" "			M			X			10 years
2. timber mortality	HIGH		not available			M						10 years
a. insect and disease					M	M						
b. fire					M	M						
c. past fires	MODERATE				M*	M*	M					
3. reforestation potential	MODERATE	URA	not complete			M*						Once with update
4. plantation monitoring	MODERATE							LSC or CIR				1-3 years
5. site index, assoc. soils	HIGH	URA	not available					ground survey	X			Once with update
6. erosion class	HIGH	URA						1:12,000 color or CIR	X			
7. road network and trails	HIGH	URA			M	M	M					5 years
8. map sensitive areas	HIGH	URA				M*						once

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/4 Large-scale color aerial photography 1:1000 scale and smaller(LSC); very large scale, aerial photography, 1:1000 scale and larger (VLSC).

Table 6.1 (con't)

BUREAU OF LAND MANAGEMENT

RESOURCE INFORMATION REQUIREMENTS

Information Desired	Desirability	Use/1	Available Data	DATA SOURCE FOR INFORMATION (Analysis Mode: Manual(M); Discriminant Analysis(DA); Multistage Approach(MA))								
				ERTS	Small Scale/1	Medium Scale/2	Conventional/3	Others/4	Ground Sampling	Thermal Infrared	Radar	Frequency of Data Collection
WATERSHED RESOURCE NEEDS:												
1. topography, geology, landform, drainage information	HIGH	URA	USGS quads	M	M	M						ONCE
2. location of streams, perennial and ephemeral springs, moist sites potential ground water	HIGH	URA/MFP	USGS quads; Dept of Water Resource maps; needs update			M						5 years
3. location of reservoirs, ponds, lakes	HIGH		incomplete; needs update	DA*		M						5 years
4. stream channel characteristics and condition	HIGH		old black & white photos					LSC	X			5 years
5. vegetation and soil type	HIGH	URA	SCS maps; range surveys					LSC (for veg map)	X			10 years
6. erosion condition assessment	HIGH		not available					LSC	X			biannual
7. watershed treatments and improvements						M						
8. snow mapping	MODERATE		not previously considered important	M*		M						weekly during winter seaso
9. water quality	HIGH	URA	selected streams			M		LSC	X			annually

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Table 6.1 (con't)

BUREAU OF LAND MANAGEMENT

RESOURCE INFORMATION REQUIREMENTS

Information Desired	Desirability	Use/1	Available Data	DATA SOURCE FOR INFORMATION (Analysis Mode: Manual(M); Discriminant Analysis(DA); Multistage Approach(MA))								
				ERTS	Small Scale/1	Medium Scale/2	Conventional/3	Others/4	Ground Sampling	Thermal Infrared	Radar	Frequency of Data Collection
WILDLIFE RESOURCE NEEDS:												
1. habitat type	MODERATE	URS(SPA)	Habitat surveys									10 years
a. vegetation class				a. DA*	M	M						
b. cover class						M		LSC*				
2. habitat condition	HIGH	MFP(SPA)		MS*		M		LSC	X			5 years
3. habitat trend	HIGH	SPA	photo trend plots			M			X			5 years
4. habitat production	HIGH	SPA	range surveys									Annual
a. by vegetation class						M			X			
b. planning unit				MS*				LSC*	X			
5. forage utilization		URA/MFP	range utilization studies									5 years
a. shrubs	HIGH								X			
b. grasses	MODERATE								X			
c. forbs	HIGH								X			
6. deer and anetlope	HIGH	URA/MFP	BLM field observations Dept of Fish and Game					aerial visual recon.	x			Annual

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* Assessment or judgement by UC personnel; all others by BLM resource specialists.

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/2 1:30,000 scale color-infrared highflight aerial photography, positive trans., 9 x9"format.
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BUREAU OF LAND MANAGEMENT

RESOURCE INFORMATION REQUIREMENTS

Information Desired	Desirability	Use/1	Available Data	DATA SOURCE FOR INFORMATION (Analysis Mode: Manual(M); Discriminant Analysis(DA); Multistage Approach(MA))								
				ERTS	Small Scale/1	Medium Scale/2	Conventional/3	Others/4	Ground Sampling	Thermal Infrared	Radar	Frequency of Data Collection
MINERALS												
1. structural geology										M*	M*	
2. geothermal detection										M*		
3. monitoring minerals extraction and environmental impact				M*	M*			subsample w/ LSC or CIR				
RECREATION NEEDS:												
no information available												
LANDS NEEDS:												
no information available												

/1 Unit Resource Analysis (URA); Management Framework Plan (MFP); Analysis Planning (AP)

* Assessment or judgement by UC personnel; all others by BLM resource specialists.

/1 1:120,000 scale color-infrared highflight aerial photography, positive trans.,9 x 9"format
/2 1:30,000 scale color-infrared highflight aerial photography, positive trans., 9 x18"format
/3 1:15,840 scale black-and-white aerial photography, print, 9 x 9" format.
/4 Large-scale color aerial photography 1:1000 scale and smaller(LSC); very large scale, aerial photography, 1:1000 scale and larger (VLSC).

Table 6.1 (con't)

APPENDIX E

ANNOTATED BIBLIOGRAPHY OF SAMPLE SURVEY APPLICATIONS OF REMOTELY SENSED DATA

This bibliography summarizes application of remotely-sensed data to sample surveys of wildland environments. It includes primarily forestry applications with few references found in other areas. References published since about 1970 have been reviewed.

The presentation is in two parts. The first is more detailed and summarizes each reference according to 1) Objectives, 2) Design, 3) Methods, 4) Equipment, 5) Variables used, 6) Cost, and 7) Conclusions. The second summarizes very briefly other references which because of their generality did not reasonably fit the annotation format of the first part. Each part is alphabetical by author.

Aldred, A. H., Kippen, F. W., 1967, Plot Volumes from Large-Scale 70mm Air Photographs. For Sci. Vol. 3 no. 4 pg. 419

Objectives: To devise and test a method for estimating plot volumes from tree measurements on 1:1200, 70mm photography.

Design: Simple Random Sampling of mixed softwoods and hardwoods in a strip of the Petawawa Forest Exp. St. in Ontario

Methods:

1. 15 phots were chosen at random from 120 photos in the strip.
2. A circular 1/5 acre plot was established at the central point of each photo. Plot size and distortion of form were controlled by radial line plotting.
3. Trees taller than 20 ft. occuring inside the plot were numbered, identified, and measured.
4. Field measurements were made after photo work was completed.

Equipment: 1. 70mm Vinten camera with 12" focal length and a focal plane shutter at 1/3000 sec. 2. Panchromatic Super Hypan film, with photos enlarged 4 times. 3. Total height was measured on photos with a Zeiss Stereometer under 6x magnification, crown area with a 100 or 400 dot/in^2 grid, and dbh with a 10 to 30 power Bausch and Lomb Zoom Macroscope with measuring reticle.

Variables: Regression equations were constructed by species for determining dbh and volume from crown area and height of the form:

$$D = a + b\ (H \times CA) \text{ or } D^2 = a, + b, (H \times CA)$$

Photo to field correlations dbb

pine	r = .92
spruce or fir	r = .96
Hardwood	r = .96
Species ID,	96%
SE Volume = 8.1%	

Cost: Cost of photo plots were $5 to $10 per 1/5 acre plot

Conclusion: Large scale photography could be expected to improve the efficiency of a timber survey system particularly in remote areas where field sampling is expensive.

Aldred, A. H., Hall, J. K., 1973, Applications of Large-Scale Photography to a Forest Inventory. For chron. Vol. 51 no. 1 Feb. 1975

Objective: To test and to establish the cost effectiveness of a method of forest inventory using Large-Scale Aerial Photography.

Design: Stratified 2-stage cluster sampling of mixed conifers on a 3200-acre area in western Quebec, north of Maniwaki, with 1) strips selected on the basis of SRS, 2) strips selected on thebasis of PPS, plots selected with equal probability in both models.

Method:

1. The forest area was stratified into 2 strata based on species using 1:20000 photography.
2. 10 strips and 30 plots were selected according to design and the plots sampled with Large Scale Photography.
3. On 8 plots, field data were collected to check the accuracy of the photo work.

Equipment: A Venten 518, 70 mm camera with a focal length of 153.29 mm; Panchromatic 400 ASA Agfa Pan 36 film.
Photo measurements were made with a digitalized zeiss stereoscope.

Variables: Total height and crown area were measured on photos to construct dbh and volume equations of the form:

$$V \text{ or } D = b_0 + b_1 H\sqrt{CA} + b_2\sqrt{CA}$$

Total Volume = 17535 m^3, with a SE of 15%

Costs: Costs not common to both conventional and LSP inventory methods were enumerated.

		LSP Method		
	conventional	FMI Man days	$	$ per/ Photo Plot
Equipment depreciation	negligible	-	2000	-
Aircraft rental	-		2400	-
Equip. insta. and test flights	-	8	327	
flight personnel	-	3	100	-
Film (3 rolls, 70 mm)	-	-	36	.57
Processing	-	2	220	3.44
Annotation	-	3	142	2.25
Photo measurement (63 plots)	-	8	286	4.54
Computer processing of photo data	-	2	163	2.58
Field measurements (60 plots)	6000	-	368	-
	$6000		$6042	$13.38

Conclusions: The success of the method depends on its use in extensive inventories of remote areas, or areas where access is difficult and expensive.

Aldrich, Robert C., 1971, Space Photos for Land Use and Forestry. Photogrammetric Engineering Vo. 37:4

Objectives: To determine the usefulness of Apollo 9 photos for stratification in forest inventory.

Design: 5 stage design using PPS sampling for about 15000 square miles in Mississippi and Georgia.
1st stage: 1:2,430,000 scale Apollo 9 photos;
2nd stage: 1:60,000 aerial photos;
3rd stage: 1:12,000 aerial photo;
4th stage: 1:2000 aerial photo;
5th stage: Ground plots.

Method:
1. Apollo 9 photos of the areas were divided into 4-mile square blocks.
2. 5 blocks were selected with probability proportional to predicted volume (based on the proportion of forest for each block), and aerial photos were taken at 1:60,000
3. Each selected block was divided into 12 strips. 2 strips from each block were sampled with probability proportional to proportion of forest and photographed at a scale of 1:12000. 1:2000 scale photos were taken at 7-10 second intervals.
4. The 1:2000 scale photos were divided into 4 equal squares of 0.625 acre. Volume was predicted using a modified aerial volume table.
5. One .625-acre plot was selected by PPS in each strip for ground measurements. These plots were 100% enumerated on the ground and dbh measured. Two or 3 trees were selected from the list with PPS for both hardwood and softwood on each plot.

Equipment:
1. Hasselbland 70mm camera with 80mm focal length, and 50-180 Ekta infrared film with Photar 15 filter for 1:2,430,000 scale photos;
2. Crown graphic camera with 75mm focal length, and Poloraoid 400 film with a yellow filter for the 1:60,000 scale photos;
3. Maurer KB-8 camera with 38mm focal length, and Aero-neg film with a HF-3 filter for 1:12000;
4. Maurer KB-8 camera with 228mm focal length, and Ansco D/200 film with a IA filter for the 1:2000 scale photos;
5. Barr & Stroud dendrometer, Bausch and Lomb Zoom 70 stereoscope.

Variables: Average stand height, crown diameter and crown closure were measured from the 1:2000 scale photos, and volume estimated from an aerial volume table.

In the Mississippi area (7,680, sq. miles), volume was estimated at 2.25 billion cu. ft. of timber with a sampling error of 13%.
In the Georgia area (7,360 sq. miles), volume was estimated at 2.670 billion cu. ft. with a sampling error of 30%

Cost: None given

Conclusion: The difference in sampling error is associated with land use characteristics of the two areas, uniformity of forested areas in Miss., and the checkerboard pattern in Georgia, which affected stratification at the first stage.

Aldred, A. H., 1976, Measurement of Tropical Trees on Large-Scale Aerial Photcgraphs. Forest Management Institute, Ottawa, Ontario, Inf. Report FMR-X-86.

Objectives: To determine how well tree height can be estimated from large-scale photography.

Method: Three tests were made: (1) Height of five trees in an artificial opening were measured on phots of 2 scales; (2) All trees larger than 20 cm dbh within a .25 ha plot were numbered, identified, and measured in the field. Tree height and crown area were measured for the 39 trees visible on the photo plots. (3) photos were taken at elevations of 270 to 700 m on three film types. 14 openings in the canopy were chosen, and the parralax at each site were measured.

Equipment: Vinter 70 mm camera with 150 mm focal length; Zeis RMK 15/23; GTW low-level radar altimeter; ADL tilt indicator; Zeis steropret w/6x magnification Wild microsterocomparator w/6x magnification; panchromatic B&W color infrared transparencies and prints, and normal color transparancies and prints.

Variables: Test (1) Tree height was measured within $\pm$ 1m about two-thirds of the time.

Test (2) Tree height was measured within $\pm$ 4m about two-thirds of the time. Bias accounted for about 2m. Crown area was measured and a linear regression of dbh on the square root of crown area obtained r = .51

Test (3) Parralax could be measured down to 20m of the 27m stand under the best conditions tested.

Conclusions: Tree height can be measured with sufficient accuracy on large-scale areal photos provided that the forest canopy is sufficiently open or that the terrain is flat.

Aldrich, Robert C. 1976, Evaluation of Sky_lab (EREP) Data for Forest and Range Surveys. USDA For. Serv. Paper PSW-113

Objective: To test the potential for application of Skylab data to land use classification and forest area determination.

Design: Cluster sampling

Method: Ground truth was established by a combination of field plots, high altitude aerial photography and 1:20,000 aerial photographs.

1. 25 clusters of 16 points on a 1:20,000 aerial photograph were classified into 5 land use classes.
2. These clusters were located on Skylab photographs and the points classified by land use. Using 3 combinations: (1) a color and false-color 1:25,000 enlargement evaluated without steroscopic effect (2) a color and false color 1:500,000 enlargement evaluated without sterescopic effect; (3) the 1:500,000 scale enlargements evaluated with sterescopic effect.
3. 40 sixteen-point photo clusters that had been subsampled on the ground in the 1971 forest inventory were located and interpreted.
4. These 3 sets of data were compared with ground truth by computer.
5. A second test was made using the stereopairs of 1:500,000 scale photos. 210 sixteen-point clusters were classified on aerial photos, skylab photos, and on the ground and analyzed by both grouped and individual land use classes.
6. A third test was made to determine whether Skylab photographic data could be used to measure forest area within specified accuracy limits. The grouped land use class was recorded for each point on a grid overlay of 16 point clusters. Forest type and disturbance were recorded for each cluster center.
7. Automated land classification was tested, and the accuracy checked by comparing proportion of areas in land use classes with the ground truth map, and by checking 480 points for which ground truth had been determined.

Equipment: Zoom Transfer Scope, Old Delft scanning stereoscope, Photo Data Systems microdensitometer and companion model 2300 process computer, Electronic Associates, Inc., tape-driven plotter, CDC7600 computer.

Variable: Forest conditions were evaluated on the basis of stand origin, physiographic site, forest type, and treatment class. The classification of stand origin (natural or artificial) was unsuccessful because of low resolution. In the classification of physiographic site, 90 percent of the plots fell in one category. Accuracy was 99%.

Forest types were classified correctly only 50% of the time. When pine, and pine-hardwood plots are combined into single class the accuracy increases to 70%. Classifications of treatment class were made on Landsat, Skylab, and CIR high altitude aerial photography. Accuracies were 63%, 80% and 80% respectively.

In the intensive sample for forest area, Skylab proportions were 3% higher (unadjusted) than proportion based on 1:20,000 scale photos. In the 40 subsample cluster the Skylab proportion was 3% lower than ASCS 1:20,000 photo proportion. Adjusted proportions were:

Skylab, 45,741 ha ± 3.53%
ASCS, 42,123 ha ± 3.17%

Using automated land classification forest area was stratified on Skylab photographs with an accuracy of 96%, pine and hardwood were separated with an accuracy of 70%

Cost	Cost	
	ASC 1:20000	Skylab
Photo handling	$140	$125
Photography cost	$366	$100
Photo-interpretation	$36.35	$50.90
Total	$542.35	$275.90

Cost of stratification using Skylab photographs is 47% of cost of using ASCS 1:20,000 scale photography.

Conclusions: Skylab photographic data was useful for broad classification of land use classes, such as forest (deciduous and coniferous), and nonforest.

Avery, T. E., Canning, James 1973, The New Zealand Journal of Forestry No. 18(2)

Objective: To determine the precision of photographic measurements of CD,H,Stems/ha and their value in predicting BA and volume for thinned stands of Pinus radiata.

Design: Non outlined

Method:
1. 20, 400m^2 circular plots were established and marked on the ground to aid in determining plot location and scale on the photographs.
2. Trees were 100% enumerated in the field and dbh, height, and crown diameter were measured.
3. Photographic coverage of the study area was obtained at a scale of 1:3000.

Equipment: Zeiss RMK-A-60/23 aerial camera having a 30° lens angle and a 24" focal length.
Kodak Aerocolor film, type 2445

Variables:

	No. of Stems Field Count	Ave. Photocount (6 interpreters)	# within ± 2 trees
B&W	304	303.67	3
Color	304	305.83	4

Interpreters were within 1.8m of field measured tree height an average of 96.6% of the time on color and 86.7% of the time using B&W film.

Interpreters were within .6m of field measured CD 91.5% of the time using color film and 85% of the time using B&W film.

dbh was calculated using a regression equation of the form:

$Y = a + b(CD)$, $r = .843$

Costs: None reported

Conclusions: Photo interpretation is improved with the use of color film. Tree height and crown diameters can be accurately measured using aerial photography.

Bonner, G. M., 1974, The Error of Area Estimates from Dot Grids. Can. Jour. of Forest Research, 1975, 5(1):10-17

Objectives: To determine if the error of area estimates from single dot counts can be predicted.

Method: 14 areas, ranging in size from .13 in. to 22.19 in. were measured five times with a polar planimeter. The average areas were used as "true" areas. The area and the area combinations were assigned to one of four Area-Shape classes. Each area was measured 10 times with each of five dot grids, of densities 10, 25, 50, 80, and 100 dots per in^2. The sample count was compared with the "true" count, and percent error (e%) was calculated.

Results: If e% is plotted over N on double-log paper, a well defined relationship results. Regression equations were derived for log e% from log N, N = Area x Density of the form Y = a-bx.
a, b, and S^2 were figured for the Area-shape classes. To determine density, D, needed on a dot grid for a specified error, the equation

$$D = \frac{1}{A}\left(\frac{C}{E\%}\right)^{1/b}, \quad C = \text{antilog } (a + tS)$$

was derived.

Costs: A time study was made in conjunction with the test counts. Results showed that time differences between grids and between Area-Shape classes are significant.

Conclusion: The ease with which error levels can be estimated and low error levels attained should contribute to better forest inventory data.

Bonner, G. M., Aldred, A. H., 1975, Large Scale Aerial Photography in Forest Inventories: Designs and Applications. Proc. Inventory Designs and Analysis Workshop, SAF, Ft. Collins, Col., 23-25 July, 1975.

Objective: To compare a 2-stage cluster sampling design for use with fixed-winged aircraft, with a double-sampling, helicopter design.

Design:

Phase I -- construction of tree volume equations
Phase II -- Fixed winged --
1. Stratification
2. Each stratum divided into narrow clusters of varying lengths.
3. Each cluster divided into 1/5 acre rectangular plots.

-- Helicopter --
1. Stratification
2. A large number (m) sample plots are randomly selected from a strata
3. Photo-volume estimates are obtained.
4. A small, random subsample (n) plots are selected and measured on the ground to obtain plot volume estimates.

Method: Phase I. Approximately 100 trees were selected at random from each species group, and measured on photos and in the field.

Phase II. Fixed-wing cluster sampling:
Species were stratified into classes, one predominately spruce and fir, the other pine.
A sample of 10 clusters and 30 plots were arbitrarily selected with equal probability, plots with probability proportional to cluster size.
Height and crown area were measured on the photo plots and applied to tree-volume equations to yield plot volume estimates.
-- Helicopter --
No test of this design was given.

Equipment: None identified

Variables: Height and crown area were measured to construct volume equations, for each species of the form:

$$V = b_1 + b_2 H \sqrt{CA} + b_3 \sqrt{CA}$$

Results for the cluster sampling design are:

Species group	Mean Plot Value ($ft.^3$)	SE %	Pop. volume ($ft.^3$)
Spruce	37.16	16.1	519,311
Fir	72.76	19.9	1,016,821
Jack pine	5.43	94.9	75,884
Red & White pine	81.26	24.6	1,135,608
All	170.57	14.4	2,383,716

The correlation between plot volumes measured on the ground and on photos was .982 on 22 1/5 acre plots in E. Canada.

Cost: In the linear cost function for the double sampling design $D = C_o + mC_2 + c_3$, C_o was estimated at \$4000, C_2 at \$15 and C_3 at \$100. The optimum ratio of

$$\frac{m}{n} = \left(\frac{r^2}{1-r^2} \frac{c_3}{c_2} \right)^{\frac{1}{2}}$$ was 14 to 1.

Conclusions: Cost factors make fixed-wing aircraft preferable over helicopter for forest inventory. The use of LSP in partial replacement of fieldwork is a practical alternative to conventional sampling.

Bonner, G. M., Cluster Sampling with Large-Scale Aerial Photography in Forest Inventories. Canadian Forest Service Dept. of the Environment June 1975, Information Report FRM-X-80

Objectives: To present and apply a design for using LSP as a primary source of information in forest inventories.

Design:

Sample one: data are obtained for tree-volume estimators for each species, from field and photo measurements of individual trees by Simple Random Sampling

Sample two: Model (1) Stratified cluster sampling, clusters selected by SRS, plots proportional to cluster size.
Model (2) Stratified cluster sampling, clusters selected by PPS with equal number of plots per cluster.

Proportional allocation of clusters to strata.

Methods:

Sample one: 100 trees per species were selected randomly. Height and crown area were measured on photos, the trees felled and measured on the ground.

Sample two:
1. The population was stratified into 2 strata using existing cover type maps or small-scale photography.
2. Each stratum was then divided into long, narrow strips, or clusters (ave no. plots/cluster = 14), of unequal length.
3. LSP was obtained of a proportion of these which were divided into .08 ha plots, a proportion of which were sampled in model 1. 3 plots per cluster were sampled in model 2. 10 clusters and 30 plots were arbitrarily selected for sampling for each model and allocated to the two strata.

Equipment: None mentioned.

Variables: Height and crown area were applied to equations of the form

$$Y = b_1 + b_2 H\sqrt{CA} + b_3\sqrt{CA}$$

or both models the estimated plot mean is

$$\bar{\bar{Z}} = \frac{1}{m} \sum_{h}^{L} \sum_{i}^{nL} \sum_{j}^{m_{hi}} Z_{rhij}, \quad A_{rhij} = \text{value of LSP variable r in plot of j of cluster i in stratum h.}$$

$$m = \text{no. of plots.}$$

Variance estimator

Model 1

$$S'^2_{\bar{\bar{Z}}_r} = \frac{1}{\bar{M}^2}\left[\frac{1-f_i}{f_i}\sum_{h}^{L} N_h S_{1hrr} + \frac{1-f_2}{f}\sum_{h}^{L}\sum_{i}^{N_h} M_{hi} S_{2hirr}\right]$$

Model 2

$$S''_{\bar{\bar{Z}}_r \bar{\bar{Z}}_r} = \frac{1}{\overrightarrow{M^2}} \sum_{h}^{L} \frac{n_h}{n_{h-1}} \sum_{i}^{n_h} \left(Z''_{rhi} - \bar{Z}''_{rh} \right)^2$$

Standard error as a % of V for all species in model 1 was 23%, in model 2, 14%. Variance of the Mean for model 1 was .105, for model 2, .175.

Costs: $C = (C_1 + C_2\bar{M} + C_3 m)n$

C_1 = Traveling cost, $C_2\bar{M}$ = Photo cost per plot of a cluster, times average no. of plots per cluster, $C_3 m$ = cost per measured plot times average no. of plots sampled per cluster, n = number of clusters in the sample.

C_1 = \$14 C_2 = \$.04 C_3 = \$10

Conclusion: The sampling design presented here should help make LSP a useful tool in forest sampling and inventories.

Cosgriffe, N. R., J. M. Linne, M. P. Meyer, Forest and Rangeland Resource Inventory with Small Scale Infrared Aerial Photography. Institute of Agriculture, Remote Sensing Laboratory, Research Report 73-4

Objective: To evaluate surface resources on 900,000 acres of land involved in possible strip-mining leases.

Design: Mapping approach

Method: The area was photographed at a scale of 1:40,000. Resource features and vegetation types were delineated on thermofax contact-size transparent overlays. Information was transfered to a 1:125,000 scale work map using at least three control points.

Equipment: RC-10, 9x9 inch format aerial mapping camera, Aerochrome infrared type 2443 film, Wratten 12 filter.

Cost: $15,700 for the entire area, $0.0063/acre.

Conclusion: This method provides the resource managers with a tool for gathering assembling, and graphically displaying reliable resource data and is invaluable for supplementing land use planning efforts and preparation of Environmental Impact Statements.

DeSelm, H. R., Amundson, C. C., Krumpe, P. F., 1972, Prediction of Site and Cover Parameters. Proc. Tenth Annual Institute of Electrical and Electronic Engineers, Inc., Region 3 Conference, Knoxville, Tenn. April 10-12, 1972.

Objective: To determine the usefulness of aerial photographs in determining species composition, stand density, tree diameters, understory, mortality, and soil and topographic features in hardwood stands.

Methods: Ground Data was acquired on two one-fifth acre plots and at other points which were readily recognized on film. Autum and winter imagery was obtained at scales from 1:3900 - 1:10,000.

Equipment: Hasselblad camera system, Ektachrome 2448 and Ektachrome Infrared Areo 8443 films.

Variables: Regression estimates were computed for ground measurements and photo variables. 70% of the tree taxa, representing 90% of the trees present, were identified, and a key prepared using crown color, color distribution, and 33 crown structural characteristics.

Conclusions: Mapping and assessment of hardwood vegetation types is possible using remote sensing.

Dodge, Arthur G., Bryant, Emily S., 1976, Forest Type Mapping with Satellite Data. Journal of Forestry, August, 1976.

Objectives: To test the effectiveness of using Landsat Data for forest type mapping in New England.

Design: Choose a training site and identify signatures for forest and other cover types; Apply the signatures to a test area; Apply the signatures to an entire county.

Method: 1. Three training sites were selected. Ground truth was established using forest type and land use maps, 1:12,000 color aerial photography 1:20,000 B & W aerial photography, and 1:13,000 infrared aerial photography. Forest types were located and verified in the training sites. A sample of 12 pixels was chosen and 4 band averages were used as signatures of forest types.

2. The signatures were applied to a larger test area, and corrections made.
3. The signatures were applied to Coos County, and Cheshire County, New Hampshire.

Results: Computer measured acreages of hardwood, softwood, and total forest area within 10% of U.S. Forest Service Statistics.

Costs: Costs for Cheshire County totaled $.01 per acre. Once the signatures are made, they may be applicable to a number of counties, reducing the cost.

Conclusion: Landsat data offer useful and potentially low-cost information for mapping general forest types.

Graves, H. B., Bellis, Ed, 1971, Censusing White-tailed Deer by Airborne Thermal Infrared Imagery. Journal of Wildlife Management Vol. 36, No. 3 June, 1972

Objectives: To test the effectiveness of 2 infrared detector systems, scanning from different altitudes, in detecting, enumerating, and tracing the movement patterns of white-tailed deer.

Design: None mentioned. A two mile wide corridor south of Highway 80 in north-centeral Centre County, Penn., including an eight mile section of the highway, was the main census area.

Methods: Nine parallel flight lines were drawn on a US Geological Survey Map of the area so that some overlap would occur along adjacent runs. Imagery was obtained for the entire area 5 times between 4:35 pm and 5:30 am. The presence and location of deer spotted from a ground vehicle on the highway were recorded by reference to wooden stakes placed at 200 ft. intervals along the 8 miles of highway in the study area.

Equipment: Two types of infrared detectors were used: an Indium Antimoxide (In Sb) dector most sensitive in the 3-5 micrometer range; and a Mercury Cadmium Tellwide (MCT) detector most sensitive in the 3-14 micrometer region. The system had a scan speed of 12000 rpm. The 4 sided scanner provided 800 scans/sec. The infrared imagery was interpreted using a Bausch and Lomb magnifier.

Variables: Targets identified as potential deer were circled on the film. Positive images were determined by comparing images over the same area at different times. Overall, about 6% more deer (61:57) were sighted by infrared imagery than by vehicle.

Cost: None mentioned.

Conclusion: Selection of a specific infrared detector depends on the general environmental conditions present and the type of target to be detected. Deer emit enough energy in the 3-5 micron range to allow detection by airborne infrared equipment operated under certain conditions.

Haapala, Fred H., Neuman, Paul O., 1972, Determining Stocking of Conifer Reproduction with Large-Scale Color Infrared Aerial Photography. State of Washington DNR Report No. 28

Objectives: To test the feasibility of determining stocking of conifer reproduction in scrub Red Alder and non-commercial hardwood from large scale infrared photography.

Design: No design was given. The study area was a 12-acre stand of hardwood that had been sprayed and underplanted with 1 - 2 Douglas fir 2 years prior.

Method: 1. The area was photographed with infrared film at scales of 1:12000, 1:2400, 1:4800.
2. The area was visited on the ground to relate shape, size, and color.
3. The number of trees was counted on an area of about 1.5 acres at each of the scales by two interpreters.

Equipment: Color infrared film, 6" focal length camera.

Variables: Out of 152 conifer trees, up to 6" in dbh, 47 were identified by photo interpretation on a .6 acre rectangular plot. Accuracy was not given for the 1.5 acre plot.

Cost: Not given

Conclusion: Large-scale color infrared photography has potential for detecting conifer reproduction greater than 3 feet tall with crown diameter greater than three ft.

Heller, Robert C., 1975, Evaluation of ERTS-1 Data for Forest and Rangeland Surveys. USDA For. Serv. Res. Paper PSW-112

Objectives: To study the usefulness of ERTS-1 data in Landuse classification, vegetation classification, and forest disturbance detection.

Design: Simple random sampling.

Method: Ground truth was established from high altitude underflights and ground checks. An overlay of 292 random sample units was attached to the ERTS scene. Each interpreter made an independent interpretation of Landuse classification on color composites of two seasonal combinations. For disturbance detection, interpreters classified 245 locations as to type of disturbance and landuse trend. Computer-assisted mapping techniques developed by LARS were tested and compared with PSW techniques.

Equipment: Old Delft stereoscope, Bausch and Lomb Transfer Scope, CDC7600 computer.

Results: Land use classes were accurately classified (forest or non-forest) 96 per cent of the time. Vegetation classification accuracy was not acceptable. Overall accuracy of detection and classifiction of forest disturbances was 79%. Computer assisted classification distinguished forest from non-forest 94-96 percent of the time.

Conclusion: ERTS-1 data provide a good Level I land-use classifier for forest inventory and can be useful in detecting forest disturbances. Classification can be done most effectively by computer, but photointerpretation is just as accurate.

Hitchcock, Hancy, C. III, 1974, Constructing a Aerial Volume Table from Existing Tarif Tables. J. of Forestry 72(3):148-149

Objectives: To develope a technique for construction of a single-variable volume table for open-grown Ponderosa Pine.

Method:
1. A volume table was constructed and a dbh to height relationship defined for 58 young-growth Ponderosa Pine.
2. A tarif number was calculated for each of the 58 stems.
3. A crown diameter to dbh relationship was defined by sampling 600 trees in 15 randomly selected 15-acre tracts.
4. The CD-dbh equation was used to convert crown diameters to dbh and volumes were extracted from the tarif table.

Equipment: Bar & Stroud dendrometer

Variables: $V = 0.211996 + 0.00185D^2H, {}_2r^2 = .985$

$dbh = -0.323 + 0.759\ CD, r^2 = .802$

Conclusion: The procedure developed eliminates height, measurement for volume estimation from aerial photographs.

Jobin, L., Beaubien, J., 1974, Capability of ERTS-1 Imagery for Mapping Forest Cover Types of Anticosti Island. Forestry Chronicles 50(6):233-237

Objectives: To examine the possibility for mapping broad vegetation cover types, and for monitoring extreme insect damage to forest.

Methods: Visual analysis of satellite black and white, and color composite images were checked against ground truth by helicopter surveys, and by high altitude aerial photography. The photos were examined for vegetation, cover types, burns, cuts, insect outbreaks, and terrain features, and mapped at a scale of 1:250,000.

Results: ERTS imagery was useful in identifying general mapping units. Different spectral bands and various seasonal scenes enhanced interpretation of different forest features.

Conclusions: Satellite imagery shows promising possibilities for mapping broad cover types and insect damage. Interpretation could most likely be improved by photographic or electronic color enhancement, optical color combiner or computer analysis.

Johnson, G., Ulliman, J., Zasada, Z., Meyer, M. Application of 70 mm Aerial Photography to Mechanized Timber Harvest Disturbance Assessment. Minn. Forestry Research Notes 1973, No. 246.

Objectives: To determine the usefulness of using aerial photography for assessment of timber harvest disturbance.

Method: A site was clearcut using a full tree system with most slash and debris removed from the site. 1:2000 scale color infrared PHOTOS WERE obtained and 140 test cells classified by 5 interpreters into 7 classes (rutted soil, bare soil, turned duff, litter, shrubs, herbacaous plants, slash), on the photos and on the ground.

Equipment: Ektachrome infrared film with Wratten 15+ Color Compensating 20C filter.

Variables: In all, 52% of the test cells were correctly identified. When litter, duff, and shrubs were combined into one class, the accuracy increased to 86%.

Conclusion: Based on a combination of classes this study proved successful.

Kalensky, T., Scherk, L. R., 1975, Accuracy of Forest Mapping from Landsat Computer Compatible Tapes. Proceedings; Tenth International Symposium of Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 6-10, 1975.

Objective: To determine the accuracy of forest mapping from Landsat computer compatible tapes using single-date and multi-date classification.

Method: Ground truth was provided by medium-scale aerial photographs, forest cover maps, and spot field checks. Image data were classified by the Gaussian Maximum Likelihood Decision Rule and displayed by alphabetically coded computer print-outs and by color coded film images.

Equipment: Image 100 processing system, Electron Beam Image recorder, Digital Color Image Recorder (DICOM).

Results:

	Classification accuracy %		Mapping accuracy %	
	Range	Ave.	Range	Ave.
Single-date	67-81		55-72	
Multi-date	82-83	82.5	72-74	72.5
Md bands 5 & 7	--	84	--	75

Conclusions: The results obtained confirm the usefulness of the Landsat computer compatible tapes for automatic identification of forest and classification of broad forest types.

Kirby, C. L., Johnstone, W. D., 1970, Estimation of Lodgepole Pine Diameter, Basal Area, and Stand Volume from Measurements on Large-Scale Aerial Photographs. For. Research Lab, Edmonton, Alberta, Info. Report A-X-37

Objective: To test the efficiency of two techniques for estimation of diameter, basal area, and stand volume from large-scale aerial photos.

Design: None outlined. The population was 110 year-old stand of lodgepole pine in the Subalpine Forest Region.

Method: 5, square, tenth-acre plots were selected. Trees were 100% enumerated on the ground and species, dbh, crown width, and height were determined. Average stand height and volume were measured using point sampling with 81 points, per 1/10-acre plot. Aerial photos were taken at a scale of 1:2400, and measurements of height and crown width obtained for each tree in the photo.

Equipment: "Vinten" 70mm camera, 305mm lens, f. 5.6, 1/500 sec.
Ansco Super Hypan panchromatic film

Variables: Crown width, tree height, and crown closure were measured and dbh and volume were estimated by two techniques.

(1) $D_1 = 3.13 + .012\ (cw)x(ht), r^2 = .78,\ SE_E = 85"$

(2) $D_2 = 13.26 + 8.24\ \text{Log.}_{10}\ (cw)\ (ht),\ r^2 = .82,\ SE_E = 78"$

(1) $V = \frac{cc \times 43{,}560}{K^2} \times (4.4)\ (\overline{H}_{10})$

where $K^2 = \frac{CW^2}{D^2}$, $\overline{H}_{10}$ = ave. height of the 10 tallest trees

(2) $V = .005454\ D_2^2\ (\text{No. stems/acre}) \times (4.5 + .44\overline{H})$

where $4.5 + .44\overline{H}_{A11}$ = Volume to Basal Area Ratio

	Ave. Ground Volume for 5 plots (cu. ft)	Ave. photo volume for 5 plots (cu. ft.)
Analysis 1.	4539	4567
Analysis 2.	4539	4446

Costs: None reported.

Conclusion: None

Kirvida, Leon and G. R. Johnson, 1973, Automatic Interpretation of ERTS Data for Forest Management. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Goddard Space Flight Center, March 5-9, 1973.

Objectives: To determine the feasibility of automatic interpretation from ERT-A data.

Method: 1:90,000 scale aerial photographs and field checks were used to generate a ground truth map. 5 classes were delineated: conifers, hardwoods, open, water, and city. Black and white 70mm ERTS transparencies were used for orientation. Computer capatible tapes were used in automatic classification.

Multispectral and texture features of 8 x 8 arrays served as training samples. Texture was also computed on a 4 x 4 array.

Analysis: A computer classified output was compared with the training area on an acre by acre basis with 74% accuracy.

When trained and tested on independent points using only multi-spectral plus texture computed on 4 x 4 arrays, and multi-spectral data plus texture computed on 8 x 8 arrays, the accuracies increased from 74% to 90% to 99%.

Conclusions: These results indicate the feasibility of automatic stratification.

Langley, Phillip G., 1968, The Benefits of Multi-stage Variable Probability Sampling Using Space and Aircraft Imagery. Applications of Remote Sensing in Forestry, IUFRO Section 25, 1971

Objectives: A discussion of the use of Multi-stage sampling.

Design: Multi-stage sampling with constant or variable probabilities depending on the characteristics of the population.

Method:
1. Photograph of scale 1/110,000 is partitioned with a grid into primary sampling units.
2. Predict the relative amount of timber in each square. Sample the squares with probability proportional to predicted volume.
3. Rephotograph the selected squares and repeat the procedure, selecting the optimum number of subunits using the formula:

$$n_i = (\sqrt{C}\ / \Sigma^{m} \sqrt{ci})$$

4. Continue the process until a subpopulation of measurable size is obtained. At the last stage measure the volumes of the sample trees on the ground with a dendrometer, and expand the measurements to obtain volumes for the entire area.

Equipment: Wild RC8 camera, Barr & Stroud dendrometer

Variables: A two stage estimator for total volume:

$$V = \frac{1}{M} \sum^{M} \frac{1}{P_i M_i} \sum^{M} \frac{V_{iV}}{P_{ij}}$$

$$\text{one stage variance} = \frac{1}{M} \sum^{M} P_i \left(\frac{V_i}{P_i} - V\right)^2$$

Cost: None

Conclusion: When there is a high correlation between predicted and actual volumes, sampling with probability proportional to prediction results in a lower variance than equal probability sampling.

Larson, F. R., Moessner, K. E. and Flolliott, P. E., 1971. A comparison of Aerial Photo and Ground Measurements of Ponderosa Pine Stands. USDA For. Service Research Note RM-192

Objective: To evaluate the relationship between aerial photos and ground estimates of volume, basal area, aspect and slope using 3 scales.

Design: Stratified cluster sampling of uneven aged Ponderosa Pine on about 2000 acres of Beaver Creek Watershed in Arizona.

Method:
1. Photoflights were made over the study area to obtain photo scales of 1:3000, 1:6000, 1:15,840.
2. A 9-dot/in^2 grid was overlaid on the 1:15,840 scale photos, and points were stratified by aspect As warm, cool, or flat; by slope steepness; and by crown cover classes.
3. One grid point was picked at random from each stratum and a cluster of 3 plots was located along the contour around that point, staked on the ground and marked on photos for each scale. One acre plots and 1/5 acre plots were established at each point.

Equipment: A Zeiss Aerial Photo camera, focal length 8½ inches, at 1/500 sec., stop f-8. Panchromatic film. Minus blue filter.

Variables: Volume estimates from an aerial volume table, were determined from average total height and crown cover per-cent. Basal areas were obtained in the same manner.

Plot size	scale	volume correlation	BA correlation
1-acre	1:3000	.61	.71
	1:6000	.44	.66
	1:15,840	.59	.70
1/5-acre	1:3000	.72	.80
	1:6000	.75	.74
	1:15,840	.68	.78

Range of volume - - 381-4847 ft^3/acre

Range of BA estimates - - 15-220 ft^2/acre

(note: In the article, figures on % plots within one classification for aspect and slope are given)

Costs: No costs or cost functions given

Conclusions: Ground estimates were significantly correllated with photo estimates. No advantage was gained at a scale of 1:3000. However, for smaller areas, or if better resolution is desired, larger scale photos may be needed.

Lauer, Donald T., Benson, Andrew S., 1973, Classification of Forest Lands with Ultra-High Altitude, Small-Scale, False-Color Infrared Photography. IUFRO Sym. on Remote Sensing in Forestry, Frieburg, W. Germany, Sept. 18-20, 1973

Objective: To compare the relative efficiency of forest land classification with 1:120,000 scale false color infrared and with 1:15,840 scale B & W aerial photography.

Method: An area of 50,000 acres was classified with the aid of 1:15,840 scale photos; then classified with 1:120,000 scale photos. The results were compiled in map form, and evaluated in terms of accuracy of stratification, accuracy of type identification, and interpretive cost-efficiency.

Equipment: 3x mirror stereoscope

Results: Accuracy of the placement of boundaries was tested by estimating timber volume from the two maps and comparing the estimates with volume estimates from timber cruise data.

	Ground sampling	Stratified 1:15,840	Stratified 1:120,000
Volume	133.2 million board ft.	140.6 million bd. ft.	118.8 million bd. ft.
Variance	158.0 million board ft.	6.4 million bd. ft.	1.0 miliion bd. ft.
Acres of forest land	11,100	11,100	10,900
# of strata	0	41	97
# of field plots	363	310	335

Costs: The relative cost in terms of man hours of interpretive time, photo cost, and photo enlargement costs was 1:2.6 in favor of the high flight photos.

Conclusion: It appears that the forest manager could make cost effective use of ultra-high altitude, small-scale, false-color infrared photography.

MacLean, Colin D., 1972, Photo Stratification Improves Northwest Timber Volume Estimates. USDA For. Service Research Paper PNW-150

Objective: To test the relative efficiency of simple field sampling and 3 double sampling schemes for the pacific Northwest.

Design: (1) Simple field sampling
(2) Two photo strata (commercial forest and other), plots allocated proportionally.
(3) 9 photo strata--3 land use classes, with commercial forest divided into 7 photo volume classes.
(a) plots allocated proportionally,
(b) plots allocated optimally.

Method: The data used was from previous forest inventories from 1966 and 1967, The photo scale varied from 1:12000 to 1:20000. A total of 18,548 1-acre photo plots, distributed systematically were examined. Crown closure and stand height were estimated and plot volumes recorded from an aerial volume table.

From the photos, each plot was assigned to a land use class and, if commercial forest, to one of seven volume classes.

Under schemes (2) and (3a) field plots were allocated in preparation to strata area. Under scheme (3b) field plots were allocated optimally. The ratio of field to photo plots under proportional allocation was 1:16, and for optimal allocation was 1:24.

In each field plot an estimate of volume per acre was obtained from a cluster of 10 variable radius points.

Equipment: None mentioned

Variables: No volume functions were given

Relative efficiency over the entire test area, costs constant

Field plot only	2 strata	9 strata	
		Proportional	Optimal
1.00	1.26	1.96	2.11

The efficiency of the 9 strata design is about twice that of simple field sampling.

Costs: Each field plot cost $114 in NW Wash., and $90 in central Wash. Photo plots costs $0.45 in NW Wash., and $0.25 in central Wash. This is the cost of interpreter's salaries, supervision and travel, as all photos were borrowed without cost.

Conclusion: In the Pacific Northwest substantial gains are accrued when forest plots were stratified into timber volume classes.

McGreevy, M., 1974, Two Aerial Photogrammetric Methods for Measuring Small Irregular Areas. New Zeal. Jour. of Forestry 19(2):290-294.

Objectives: To determine the relative efficiency of ground measurement and aerial photo estimation of small areas of deep ripping in Kaingaroa Forest.

Method: Eleven areas, ranging in size from .08 to .4 hectare, were measured in the field with hand-held compass and chain. The areas were then photographed at scale of 1:6700 and 1:12000, and the areas estimated with a dot grid 7.6 dots per square millimeter using 2 different scale factors.

Equipment: Hasselbland Camera with Zeiss lenses of focal lengths 250mm, and 80mm. 70mm Ilford FP-4 film rated at 200 ASA.

Results: All the methods provided sufficient accuracy for practical use.

Cost: The costs of the photographic part of the test was $56 plus interpretation costs involving about 8 hours wages. Ground costs were not given.

Conclusion: Depending on the area and relative costs, ground measurement or photo measurement may be more efficient.

Nielson, U., Wrightman, J. M., 1971, Evaluation of Ultra-Small Scale Aerial Photography for Forestry: Background and Specifications of Initial Studies. Can. For. Serv. FMI FMR-X-39 Dec., 1971.

Objectives: To provide background data for project FM-90

Method: Five cameras were operated simultaneously from an altitude of 40000 (1:1600000 scale). 10 rolls of film and 5 film-filter combinations were tested. To aid in interpretation, photography at 1:3400 scale was obtained for three areas.

Equipment: 70mm Vinter camera with 3 in. lenses.

1. B & W negative film, wratten 25A filter
2. B & W negative film, wratten 58 filter
3. B & W negative infrared film, wratten 89B filter
4. Color negative infrared film, wratten 12 filter
5. Color negative film, with haze filters 3 and 5

Results:

Film-filter combination:

1. Both rolls under-exposed.
2. Both rolls discarded due to extreme under exposure.
3. Both rolls under exposed. Fair resolution on one roll.
4. Correctly exposed & processed. Excellent contrast & resolution.
5. Correctly exposed. Some contrast, but not as good as film-filter combination 4.

Conclusions: Color infrared film was the most suitable film for vegetation studies with aerial photography.

Paine, David P., Rogers, Roger A. 1971 Volume. Estimation of Douglas Fir Using Aerial Photos and PPS Sampling. Proc. ASP Tech. Sess and Sym on Computational Photogrammetry, ASP ACSM Convention.

Objectives: To evaluate several photo scales from 1:4000 to 1:12000, and determine the efficiency of photo-field PPS sampling over conventional field sampling.

Design: None detailed. The population was Douglas-fir in 4 forth-acre stands varying from 20-75 MBF/acre.

Method: (1) Three stands were divided into 40 one-acre rectangular plots each. The fourth stand was divided into 160 quarter-acre plots.
(2) Aerial photos at 4 scales (1:4000, 1:7000, 1:10,000, 1:12,000) were obtained of the area.
(3) Plots selected by PPS were 100% enumerated in the field using an average of 5 variable plot points in each 1-acre plot.

Equipment: No aerial equipment was mentioned. A 27.2 BAF prism on a wide angle Spiegle-Relaskop was used to sample variable plot points.

Variables: Localized stand volume tables were constructed from % crown closure, average crown diameter and average stand height in 50 ft. classes. The multiple correlation coefficient was .907 and the average deviation about the regression line was 36.3%.

Estimators for the total volume: $T_y = \frac{T_X}{n}\left(\frac{Y_i}{X_i}\right)$

$$SE\left(T_y\right) = \left(\frac{T_X^2}{n(n-i)}\left[\Sigma\left(\frac{Y_i}{X_i}\right)^2 - \frac{\left(\Sigma \frac{Y_i}{X_i}\right)^2}{n}\right]\left[1 - \frac{t_X}{T_X}\right]\right)^{\frac{1}{2}}$$

SE net volume was 19%

Costs: It is estimated that for ± 10% sampling error on the 160 acre tract of the study, combined photo field measurements could reduce the numbers of field plots needed by 50% to 60%. The biggest economic deterrent to this sampling method is the extra time needed to accurately locate the field plots as compared to systematically located plots in conventional sampling.

Conclusion: In many situations the number of field plots can be substantially reduced by the use of photo stand volumes and PPS selection of plots for field measurement.

Pope, Robert B., Payandeh, Bijan, Paine, David R., 1972, USDA Photo Plot Bias. For Serv. Res. Paper PNW-145

Objectives: To examine the roles of photo intensity and ground elevation in photo plot bias.

Method:
1. ASCS Photo projects from 6 counties were selected. The photos had been taken at 1:20,000 scale; ground elevation ranged from 200 - 300 ft.
2. A photo count based on a count of the effective areas per idealized township gave the proportion of photo plots that would fall in the township.
3. Each township was judged principally forest or non-forest, and its average elevation determined.

Results: Photo intensity for non-forest land exceeded that for forest land in every county. The overall photo intensity was 4.1% greater on non-forest land. The correlation between photo intensity and elevation was insignificant.

Conclusions: Irregularities in photo intensity, due in part in this study to non-uniform endlap on the ASCS photos, are not necessarily random. Any forest inventory using plots selected on aerial photos with equal probability runs the risk of obtaining biased estimates.

Poso, Simo, 1972, A Method of Combining Photo and Field Samples in Forest Inventory. Julkaisuja 76.1, Helsinki 1972

Objective: Testing and comparison of a grouping method for forest inventory with double sampling for stratification in forest inventory.

Design: Grouping method. (1) Location of photo plots, (2) interpretation of photo plots, (3) grouping of photo plots, (4) selection of field plots, (5) measurement and calculation of field plots, (6) computation estimates for photo plots, and (7) calculation of results for groups and subsets of photo plots.

Method:
1. Ground plots were based on tract-wise sampling and located using a dot grid overlain or photographed on aerial photos of scale 1:2200. 1536 photos were taken in 1967 and 2612 photos were taken in 1968.
2. The photoplots were sorted into land use classes. Swamp and bare soil were separated. Emphasis was placed on volume and nutrient content, while species composition, treatment class, moisture content and stoness, and degree of drainage received less weight.
3. Field plots were selected randomly, one for each group. Combinations of group size and interpreters resulted in a range of 78 - 179 recognized groups.

Variables: Plot volume to field volume

$$S_y^2 = 3405 \ (M^3/ha)^2$$

$$S_{y.x}^2 = 1286$$

$$\text{mean} = \frac{1}{N} \sum_{k}^{M} \sum_{i}^{N} y_{ki} \qquad y = \text{variable of population point i from group number k}$$

Total variance V = Variance between groups (V_i) + Variance within groups (V_2)

$$V_i = \sum_{k'}^{m'} \frac{W_{k'}^2}{m_{k'}} \left(S_{y.\,x\,k'} + b_{k'}^2 \sum_{k}^{m_{k'}} S_{xk'}^2 / m_{k'} \right)$$

$$v_2 = \sum_{k}^{m} W_k \ (y_k - \bar{y})^2 = b_k^2 \ S_{xk}^2$$

Costs: The grouping method was more efficient (lower variance for a given cost) than systematic sampling in mean volume on total area and determining the estimation of proportion of forest land. The grouping method was slightly more efficient than double sampling for stratification but less efficient than systematic sampling in determining total volume on forest land.

Conclusion: Flexibility arising from the treatment of each photo plot as a separate unit makes the grouping method an attractive model for forest sampling with aerial photos.

Rhode, Wayne G., Olson, Charles E. Multispectral Sensing of Forest Tree Species. Photogrammetric Engineering V. 38:12

Objectives: To demonstrate the effectiveness of computer analysis of multispectral data in determining tree species.

Design: None outlined

Method: Multispectral data were collected in 10 bands at an altitude of 1500 ft. Various types of photography were obtained at the same time. Spectral signatures of objects to be recognized were obtained for areas where ground data was available and fed into the computer. The computer calculated the mean and variance of the signal for each channel and the covariance between channels. An analog plot of all resolution elements recognized as an object class was printed on photographic paper.

Equipment: University of Michigan multispectral scanner, University of Michigan Spectral Analysis and Recognition Computer.

Variables: The .46 to .48 and .52 to .55 micrometer channels were used to distinguish between conifers. The .55 to .58 and .40 to .44 micrometer channels were used to distinguish between broadlevel plants.

The results of SPARC processing were substantially better than any combination of photographic analysis.

Species recognized were: Spruce, Pine, Red Oak, White Oak, Black Walnut, Black Locust, Sugar Maple, others. Average correct identification of species was 85%.

Costs: None given

Conclusion: Tests of computer recognition of tree species using narrow-band data provided encouraging results.

Sayne-Wittgenstein, L., Aldred, A. H., 1969, The choice of Sample Plots for a Forest Inventory Using Large-Scale Photography. Forest Management Institute. Ottawa, Ontario, Info. Report FMR-X-17.

Objectives: To investigate the efficiency of different shapes and sizes of sample plots for a forest inventory by large-scale aerial photography.

Design: Simple Random Sampling of 1060km^2 area in the southern portion of the McKenzie River Delta.

Method: 20 Sample plots were located randomly on strips of photographs, and volume estimates were based on measurements made on the photos. Two shapes of plots of various sizes were examined, rectangular and cross-shaped. A cross-shaped plot with each arm 110m long and 10m wide was set up at each sample location. Each plot was subdivided into 21 ten meter by 10 meter squares. Measurement time was estimated for each size and shape. Mean plot volume, variance, and covariance were determined for the 20 plots.

Variables: Volume was estimated from tree height by the function

$$V=e^{0.0611(H)-0.9863}$$

Costs: Relative efficiency of each plot type was calculated as the reciprocal of the product of total time and the squared coefficient of variation

$$\frac{1}{T(CV)^2}$$

The 1300m^2 crossplots, with 70m arms were most efficient, followed by the 700m^2 rectangles.

Conclusion: The best sampling unit will vary with forest characteristics, operating procedures, sampling methods, and results required. It is hoped that this report will add to a growing record of experience with large-scale aerial photography.

Sayn-Wittgenstein, L., Aldred, A. H., 1972, Large-Scale Aerial Photography for Tropical Forestry. Semaine D. 'Etude des Problemes Intertropicaux, Faculte' des Sciences Agronomigues de L'Etat Gemblous 11-15 Sept. 1972

Objectives: Suggestion of a method for inventory of tropical forest using LSP.

Method: Photographs are taken at a scale in the range of 1:600 to 1:3,000. Photogrametric measurements are made of variables such as height, crown diameter, species, or numbers of trees in some class. These photographs can be used in sampling in any of a number of designs.

Equipment:
1. An aircraft that can be navigated at altitudes of 100 to 1000m.
2. A camera capable of taking up to 10 frames/sec at a shutter speed of 1/1000 sec.
3. A means of determining tilt and scale.

Conclusion: In the temperate zone LSP has been used in forestry, wildlife management, and engineering. Many applications would also apply to the tropics.

Stellingwerf, D. A., 1973, Application of Aerial Volume Tables and Aspects of their Construction. ITC Journal 1973(3):480-498

Objective: To develope and test a method for more efficient use of aerial volume tables; and to compare the conventional use of double sampling using photo and field plots, to double sampling using new aerial photos and redetermining variables on the original aerial photos which were used to compile the aerial volume table, instead of using field plots.

Design: None given. The population was uneven aged Spruce in the forest district Schneegatern, Austria.

Method: 1. An aerial volume table was constructed, using 175,.05 ha plots, from crown cover estimates on 1:5000 scale aerial photography. Determination of volume was by means of an existing field volume table.

2. The test sample consisted of 120 circular .05 ha plots. Crown area was estimated in 10% class from 1:5000 scale photographs by a person other than the constructor of the table.

3. Crown cover was redetermined on a subsample of 61 of the photos used to construct the aerial volume tables.

4. The volume was estimated in the field on 58 plots selected from the 120 photo plots.

Equipment: None mentioned.

Variables: In the construction of the aerial volume tables, % crown cover on photos, and ground estimates of volume were combined in an equation of the form:

$$V = \bar{v}h + b(c-\bar{c})$$

$r = .6845$ $V = 19.9474m^3/.05ha$ SEE = 31% $S^2_{\bar{V}} = .2245$

With the double sampling method using photo and field plots the same general equation was used.

$$V = \bar{v}g + b\ (Vphoto - \bar{V}photo)$$

$V - 21.1744m^3/.05ha$ SEE = 41% $S^2_{\bar{V}} = 2.7534$

With the double sampling method using new photos and redetermined crown cover from the photos used to construct the aerial volume table an equation was constructed of the form:

$$C_t = \bar{c}_t + b\ (c-\bar{c})$$

C_t is then used to calculate the volume using the equation for the volume table

$$C = \overline{v}g + b \quad (C_t = \overline{C}_t)$$

$V = 19.7745m^3/.05ha$ $\qquad S^2_{\overline{V}} = .6491$

Costs: For a fixed standard error of $.8057m^3/.05ha$, it was estimated that photo-field sampling would require 30 man days while photo-sampling would require only .4 man days.

Conclusions: The lower standard error and the fewer man days calculated for the proposed method of adjustment demonstrates it superiority.

Stellingwerf, D. A., 1973, Application of Aerial Photography to Gross Mean Annual Volume Growth Determination. ITC Journal 1973(5): 820-841

Objectives: The development of a method for determining gross mean annual volume growth using aerial photographs and existing growth tables.

Design: None mentioned. The population was predominately Spruce in four age classes, 40-120 yrs., in the forest district of Schneegatern, Austria.

Method:
1. Volume growth in % plot volume was determined in the field on 170,.05ha circular plots.
2. Mean crown diameter was measured for the same plots from 1:4000 scale aerial photographs, by person A.
3. Mean crown diameter was measured on another 120,.05ha photo plots by person B.
4. Mean crown diameter was redetermined on 59 plots, a subsample of the 170 growth table photo plots, by person B.

Equipment: 2 Hasselblad cameras with a focal length of 15cm.
Black and White infrared and panchromatic films.
Photo measurements were made under a mirror stereoscope with a 3x enlarging binocular.

Variables: A linear regression equation was calculated between growth in % plot volume and mean crown diameter.

$$G = \bar{g} + b\,(cd - \overline{cd})$$

$r = .7465$ $\quad S_{\bar{g}}$ (290 plots) = 1.63% of growth

A linear regressopm equation was calculated between mean crown diameter (120 plots) and redetermined mean crown diameter (59 plots)

$$CD = \overline{cd}_{+}\, b_2\, (cd - \overline{cd})$$

Growth was then calculated by

$$G = \bar{g} + b_1\, (CD - \overline{cd})$$

$G = 2.2\%$ $\quad S_G = .06242 = 2.8\%$ of G

Combined error due to volume estimation and growth estimation = 5%

Costs: None mentioned; Costs and optimum sampling fractions are examined in in Optimum Ratio of Photo-Field Plots For Aerial Volume and Aerial Volume Growth Regression Construction. ITC Report 1974.

Conclusion: Growth determination can be made using aerial photography with a savings in time required for field work.

Tiware, K. P., 1974, Area Sampling on Aerial Photographs. Indian Forester 100(7):427-435

Objectives: To test a method of determining stratum area by aerial photography and to compare the efficiency of stratum area determination by photo interpretation with that by field measurement.

Design: Double sampling using proportional allocation, with a subsample to check scale.

Method: An area of 5709 ha was photographed at approximately 1:20000 scale. The actual average scale was figured to be 1:23,000. Each photograph was stratified into Hill Sall (Shorea robusta) type, Plain Sal type, Miscellaneous type, and Non-forest. The area of each type was obtained by planimeter. 1% sampling intensity with proportional allocation was adopted for ground checks of stratum area. Out of 4333 photo plots, 43 were selected for checks. Due to a high standard error, the 43 plots were re-evaluated for elevation, and an average stratum elevation determined.

Equipment: Re. 5 camera with 114.86mm focal length lens , and panchromatic B & W film.

Results:

Stratum	Photo area SE%	Ground/photo area SE% (elevation unadj.)	ground/photo area SE% (elevation adjusted)
HS	3.68	24.69	4.14
PS	1.21	5.47	1.96
M	3.23	12.19	4.82
NF	5.8	5.8	8.12

Costs: Costs in man hours was 79 mh. For conventional ground work the time required would have been 330 mh.

Conclusion: By photo interpretatation and area sampling on aerial photographs, the forest type map and area estimates of forest types can be obtained quickly and cheaply.

Ulliman, Joseph J., Meyer, Merle P., 1971, The Feasibility of Forest Cover Type Interpretation Using Small-Scale Aerial Photographs. Proc. of Seventh International Symposium on Remote Sensing of the Environment, Vol. 11, 17-21 May 1971.

Objectives: To determine if there is any significant difference in the ability of interpreters to classify forest cover types between medium and small scale infrared aerial photographs.

Method: Sixteen interpreters were randomly assigned to four scales 1:15840, 1:31680, 1:63360, 1:90000.

Problem 1. The interpreters typed a 360-acre block, for species type, stand, height classes, and density class followed by field checking.

Problem 2. The interpreters type mapped a 640-acre block.

Equipment: Pocket stereoscopes, 70mm camera, Kodak Infrared Aerographic film, Wratten 12 filter.

Results: The Manow Whitney U test was used to analyze the 0 and 0+1 accuracy levels.

		Combined cover type, size class, density class		
Accuracy level		15/31	15/63	15/90
Problem 1.	0	.243	.443	.557
	0+1	.443	>.557	.171
Problem 2.	0	.243	.557	.557
	0+1	.100	.343	.100

There were few significant differences and no consistant trends for either increasingly larger or smaller scales on individual and combined tests. Accuracy increased on smaller scales, but not significantly.

Conclusion: Depending on the accuracy desired, essentially the same information can be obtained from small scale aerial photography as from medium scale aerial photography.

VanEs, E., Yoshi, S. C., 1974, Growing Stock Estimates from Aerial Photographs in Bastar, Madhya Pradesh. Commonwealth Forrestry Review 1974, 53(1):30-38

Objectives: To determine the best scale for forest inventory using aerial photography in the tropical deciduous forest of India.

Design: Systematic sampling

Method: Aerial photography was obtained at 5 scales from 1:5000 to 1:25000 of an area of approximately 2500 ha, and 51.1 ha circular plots were distributed over the area. The plot centers were marked with a needle on the 1:5000 scale photographs, and located in the forest. BA and volume were calculated from dbh and height. Crown diameter and crown density were also measured on the ground. Height, diameter, number of trees and crown density were measured for each photo plot. Volume was estimated from stand height and density.

Equipment: Wild RC8 camera with 15 cm lens. Mirror stereoscope with 3x magnification binoculars.

Variables: Volume was estimated from the photographs by a function of the form: $V = a_o + a_i h$. The 1:20000 scale was determined the most economical scale on which reasonable results could be obtained.

1:20000 scale	r	SEE%
height to BA	.731	30
height to V	.7155	26
density to BA	.6314	35
density to V	.6564	28

Costs: None mentioned

Conclusion: It is possible to construct aerial volume tables in the Bastar region and probably for the tropical deciduous forests of India.

Weber, F. P., Aldrich, R. C., 1972, Land Use Classification by Multispectral Scanning and Computerized Mapping. Proc. 8th Int. Symposium on Remote Sensing of the Environment.

Objectives: To test the feasibility of using MSS data in mapping land use classes.

Design: Mapping approach

Method: 4 morning and 4 midday flight lines were flown over each of the two 42-acre blocks at an altitude of 3,450 meters. The blocks were photographed with color infrared film at scale of 1:35,000. Ground crews inspected 50% of each block recording ground classification data. Data on spectral irradiance of several landscape targets, net radiation and reflected radiation was also recorded.

Equipment: University of Michigan's Multispectral Scanner, and Spectral Analysis Recognition Computer (SPARC).

Analysis: A digital print out of a red channel was produced to locate training areas for signature extraction. The digitized data was calibrated and adjusted for skew, 12 land use classes were chosen for recognition. The 4 best channels were selected and trained separately on each training set. The MSS data was then classified using the maximum likelyhood ratio method. In the second block differenences in illumination and sum angle were determined in an effort to extend spectral signatures and corrected area counts obtained.

The SPARC classification was compared with ground truth by comparing about 170 points in a block with ground classification.

Overall classification accuracy was 44% and 61% on the two blocks.

Costs: None given

Conclusions: Recognition of 12 classes is possible using MSS, but some problems in signature extension exists.

Weber, F. P., 1972, Remote Sensing to Detect Stress in Forests. Photogrammetric Engineering 38(2):163-175

Objectives: To determine the usefulness of multispectral remote sensing and automatic multispectral processing for previsual detection of damage to forests by insects, disease organisms, and air pollution.

Method: A University of Michigan multispectral scanner was flown between 1000 and 1500 ft. over forested land in the Black Hills of South Dakota. Data was obtained with a 12 channel spectrometer between .4 and 1.0 um, and 6 bands were obtained between 1.0 and 2.6 um. A UV band .32-.38 um was also obtained.

Equipment: University of Michigan Multispectral Scanner; Spectral Analysis and Recognition Computer (SPARC).

Results:

Tree Condition	Actual	Sparc Identification
old-killed pine	8	9
faded attacked pine	3	3
non-faded attacked pine	6	11

Conclusions: For optimum detection of forest stress condition it may be necessary to design special scanner systems with higher spacial resolution.

Zasada, Z., Meyer, M., Grumstrup, P., 1975, Remote Sensing Applications to Intensive Pine Plantation Management in Minnesota. Univ. of Minn. Remote Sensing Lab, Inst. Agric., For. and Home Economics, IAFHE RSP Research Report 75-3, Dec. 30, 1975

Objectives: To test the usefulness of 35 mm color aerial photography in establishing a planning base for determining stand treatment.

Method: Aerial photography at a scale of 1:25000 obtained for 383 acres of mixed confier forest in Cass County, Minnesota. The photos were used in preparation of a detailed cover type map; preparation of a selection and cutting plan; development of a skid trail plan; and selection of landing sites.

Equipment: Nikon F-2 motordrive with 50 mm lens. Ektachrome film X/2A filter. f/2.8 at 1/500 sec.

Results: Some decisions based on ground reconnaissance were altered or discarded.

Conclusions: It is recommended by the users that an aerial photography system be incorporated into the State forest management system as a regular working tool.

Aldred, A. H., 1968
Potential of Satellite photography in Forestry CFS, FMI Info. Report FMR-X-11

General article on the advantages and limitations of satellite photos as a source of information in Forestry.

Aldrich, R. C. and A. T. Drooz. 1967
Estimated Fraser Fir mortality and Balsam Wooly Aphid infection trend using aerial color photography. For. Sci. 13(3):300-313.

Fraser fir mortality was estimated using stratified-systematic sampling of aerial photos, and ground plots to adjust the photo estimates. Cost ratio of photo plots to ground plots 1:9.

Aldrich, R. C. and Von Mosch J. Greentree W.
Projection-viewer for microscale aerial photograpy. USDA PSW-227 Research Paper.

Design and use of a low-cost projection viewer for interpretation, mapping, or comparison of photographs, maps or overlays.

Aldrich, R. C. 1966
Forestry Applications of 70 mm color. Photogrammetric Eng. 32(9):802-810.

Discussed current and potential applications of aerial photography in forest inventory and in the assessment of forest damage from insects, disease, and fire.

Aldrich, R. C. and W. F. Bailey, R. C. Heller. 1959
Large Scale 70 mm Color Photography Techniques and equipment and their application to a Forest Sampling Problem. Photo. Eng. 25(1):747-753.

Discussed the equipment and methods involved in using 70 mm color film for forest inventory and damage assessment.

Aldrich, S. A. 1971
An effort to identify the Canadian Forest-Tundra Ecotone Signature on Weather satellite Imagery. Rem. Sens. Envir. 2(1):9-20

Uses low ground resolution weather satellite photography in an attempt to determine the Forest-Tundra ecotone.

Allison, George W.
An Application of An Aerial Photo Volume Table To Forest Inventory Work in British Columbia For. Chronicle 31(4):366-368.

Total gross cubic volume estimates for two areas consisting of spruce, apline, fir, and lodgepole pine, obtained by aerial photography did not differ significantly from estimates obtained from a ground cruise. The cost of the aerial cruise was 12% that of the ground cruise.

Avery, Gene 1958
Helicopter Stereo-Photography of forest Plots. Photo. Eng. 24(9):617-625

Plots were marked on the ground and vertical stereograms were taken at 200 and 300 ft. The ability to measure tree heights and crown width was slightly better on the helicopter stereograms than on USDA 1:20,000 prints.

Annonymous
CFS, Northern Forest Research Center, Edmonton, Alberta, Forestry Report Vol. 3 No. 3 Oct. 1973

Outlines several uses of space and aerial photography including a timber inventory mapping project, forest regeneration sampling, mistletoe damage, and burned area mapping.

Bentley, Jay R., et al. 1970
A Technique for Sampling Low Shrub Vegetation, by Crown Volume Classes. USDA Fs. Research Note PSW-215.

Development of a technique for estimating total biomass from shrub crown-volume

Bonner, C. M. 1966
Provisional Aerial Stand Volume Tables for Selected Forest Types in Canada. Can. Dept. For. Rural Development, Forest Branch Dept. Pub # 1175.

A step-wise multiple regression analysis was used to estimate volume from stand height and canopy density for 13 cover types in Canada.

Bonner, C. M. 1968
A Comparison of Photo and Ground Measurements of Canopy Density. For. Chron. 44(3):12-16.

Canopy density measured on the ground gave a 10% higher estimate than aerial photo estimates on 18 softwood and 18 hardwood plots.

Brun, R.
A New Stereotype Digitizer System for Measuring and Processing Large Scale Aerial Photographs. FMI Info. Report FMR-X-41, Jan. 1972.

Development of a stero-digitizer system for measuring tree height and crown area from large scale aerial photography.

Carneggie, D. m. and D. T. Lauer 1966
Uses of Multiband Remote Sensing in Forest and Range Inventory.
Photogrammetric 21:115-141

An analysis of current and potential applications of spectrozonal aerial photography, and near infrared, thermal infrared, and microwave imagery.

DeRosayro, R. A. 1959
The Application of aerial photography to stock mapping and inventories on an ecological basis in rain forests in Ceylon.
Empire For. Rev. 38:141-178

Aerial photography at a scale of 1:15840 combined with stratified random sampling was used to compile a forest type map and to estimate volume. Within major strata, standard error was ±10% at the 95% probability level.

Driscoll, Richard S., Jack N. Reppert, and Robert C. Heller 1974
Microdensitometry to identify plant communities and components on color infrared aerial photos. J. Range Manage. 27(1):66-70.

Microdensitometry successfully identified Ponderosa pine, spruce-fir, aspen, big sagebrush, native grassland, and seeded grassland communities, and was able to discriminate between some species within the communities.

Disscoll, R. S.
Color Aerial Photo - A new view for range management 1971
USDA RM 67.

Color infrared photography was used to identify range species on large scale photography.

Francis, D. A. 1957
The use of aerial survey methods in Scandinavian Forestry.
Empire For. Rev. 36:266-276

Discussion of the use of aerial photos in forest mapping -- techniques and equipment.

Frayer, W. E. 1974
The Increasing Complexity of Large Forest Inventories.
J. Forestry 72(9):578-579

Discussed general concepts of multivariate or multi-objective forest inventories.

Haack, P. M. 1962
Evaluating Color infrared and Panchromatic aerial Photographs for the Forest Survey of Interior Alaska.
Photo. Eng. 28(9):592-598

Panchromatic, infrared, and color film were compared for their usefulness in classifying vegetation type and determining tree height. Although no different in the measurability of tree height was found among the films, infrared was chosen the most suitable film for timber inventory because of the ease with which hardwoods could be distinguished from softwoods.

Heath, G. R. 1974
Earth Resources Satellites -- their potential in Forestry.
J. of Forestry 72:573-575.

ERTS imagery was used to compile a 14-class land-use map. The highest accuracy achieved was 74%

Heller, R. C. 1973
Detection of Forest Insects by Remote Sensing.
J. of Forestry, Jan. 1973:18-21.

Documents the use of normal color and color infrared films in detecting forest damage from air pollution, Dutch elm disease, oak wilt, Dwarf mistletoe, Fomes annosus, and others.

Heller, R. C. 1973
Remote Sensing in Forestry -- promises and problems.
Proc. Soc. Amer. Foresters, National Convention, Hot Springs, Ark., 1972:201-206.

Summarizes the state of the art in development and application of aerial photography, multistage photography, optical-mechanical scanners, radar sensors, satellite imagery, and automatic photo interpretation.

Heller, R. C., J. H. Lowe, Jr., R. C. Aldrich & F. P. Weber 1967
A Test with Large Scale Aerial Photographs to Sample Balsam Wooly Aphid Damage in the Northeast. J. of Forestry 65(1):10-18.

Used color photos to classify trees as dying (accuracy 95%), gouted (accuracy 75%) or healthy. Best photo scales were 1:1980 and 1:1188 depending on the severity of the damage.

Herrington, R. B. and S. R. Tocher 1967
Aerial Photo Techniques for a recreation inventory of Mountain Lakes and Streams. USDA Research Paper INT-37.

Used aerial photographs for a lake and stream inventory, gathering data such as: type, size, elevation, depth, shallow area, clarity of water, and shore cover of lakes; and stream length, width, gradient, and streambank cover. Discusses uses of the data.

Joshi, S. C. 1972.
The influence of misinterpretation on area assessment. Indian Forester 98(12):704

Misinterpretation of strata boundaries led to error in area of about 5% to 23%, using a grid with .66 cm between the dots.

Kendall, R. H. & L. Sayn-Wellgenstein 1961
A Test of the Effectiveness of Air Photo Stratification. For. Chron. 37(4) 350-355.

Stratification for canopy density, cover, height, site, age, and combinations resulted in a slight increase in the precision of estimates of volume and MAI over estimates made from systematically established permanent plots.

Kippen, F. W. and L. Sayne-Wellgenstein 1964
Tree Measurements on Large Scale, Vertical, 70 mm air photographs. Can. Dept. Forestry, For. Research Branch, Dept. For. Pub. # 1053.

1:1200 scale photographs were used to determine tree species, height, crown width, and stem diameter.

Larson, F. R. F. Folliott, P. F., Moessner, K. E.
Using aerial measurements of forest overstory and topography to estimate peak snow pack. USDA FS Research Note, RM-267.

Uses aerial photography at 1:15840 to measure crown cover and height of the overstory, and steepness and aspect of the slope, and derives an equation to estimate peak snowpack accumulation of water equivalent.

Latham, R. P. 1972
Competition Estimator for Forest Trees. Photo. Eng. Jan 1972:48-50

A method defining competitors as those trees violating an inverted cone with the apex at the base of the test tree is discussed.

Lauer, D. T. 1969
Multispectral Sensing of Forest Vegetation. Photo. Eng. 35(4)316-354.

Discussed aspects of multispectral sensing including physical properties, data acquisition, data processing, and some applications.

Lindsay, John J. 1969
Locating Potential Outdoor Recreation Areas from Aerial Photographs. J. Forestry 67(1):33-35

Compared various scales of photography (1/3600 to 1/20,000) for the ability to evaluate sites for recreation potential. Determined optimal scale to be a function of the information desired.

Lyons, E. C. 1967.
Forest Sampling with 70 mm Fixed air-base photography from Helicopters. Photogrammetria 22(1967):213-231.

Two, synchronous, boom-mounted cameras were used to obtain large-scale photos from which timber volume was estimated. For a given precision, simple photo sampling cost 15% that of ground sampling, and double sampling cost 55% the cost of ground sampling.

Meyers, M. P., R. L. Eng, R. R. Mastinka 1970
Aerial Photographic determination of Animal Movement surface area in steep terrain. Minn. For. Research Note # 212.

A technique for using aerial photography to measure small ground tract surface areas is outlined.

Murtha, P. A. 1972
Thermal Infrared line-scan imagery for Forestry. Can. For. Service, For. Manag. Inst. Inf Rep. FMR-X-45.

The use of thermal scanning in forestry was investigated. Generally some site indices could be classified, but forest type and damage was better identified on aerial photography.

Nakayama, H. 1958
A study on Forest Survey from Aerial photographs. Bulletin of Nagoya Univ. Forests No. 1

Aerial photos with subsampling on the ground were used to determine mean stand height, density, and crown diameter. Techniques for stratification and volume estimation were discussed.

Nielson, U. 1971
A new Approach to the description of the Forest Regions of Canada Using 1:160,000 Color Infrared Aerial Photography. Can. For. Services Info. Report FMR-X-35

On ultra-small scale photos distinctions between conifer and hardwood were evident and in some cases associations or individual species could be separated.

Nielson, U. 1974
Description and performance of The Forestry Radar Altimeter CFS, FMI Info. Report FMR-X-59.

Description of the radar-altimeter and results of two tests. The error is ±1% of flying height over flat terrain and about 6 meter over rough terrain at altitudes of from 240 to 1,100 meters.

Nyyssonen, A. 1975
Inventories of Tropical Moist-Forests: Information Needed and Available Techniques. Univ. of Helsinki, Dept. of Forest Mensuration and Management, Research Report 9.

A general discussion of broad information needs. Inventory techniques are not addressed directly, but several remote sensing data sources are mentioned as potentially useful including SLAR, orthophotography, satellite data, and large scale aerial photographs.

Paijamans, K. 1970
Land Evaluation by Air Photo Interpretation and field sampling in Australian New Guinea. Photogrammetria 26:77-100

Two areas of Australian New Guinea were stratified into land use types and vegetation classes distinguished.

Polycarpon, A. 1957
The Scope of Aerial Photography in stratification for sampling purposes in the Pinus bruitia forests of Cyprus. 7th British Commonwealth For. Conf., Australian and New Zealand, Vol. 5.

Twin oblique aerial photos were used for stratification, species identification, and stand density estimates. A forest type map was compiled and strata areas determined.

Sayn-Wittgenstein, L. and A. H. Aldred 1970
Error Analysis by Computer Simulation. Photo. Eng. 36:1079-1085.

Discusses a model to simulate errors of various types including ground measurement errors and photo system errors, and evaluate their impact in a sampling system context.

Stage, A. R. and J. R. Alley 1972
An Inventory Design Using Stand Examinations for Planning and programming Timber Management. USDA FS Research Paper INT-126

Uses photo interpretation of conditions in compartments and subcompartments not examined on the ground.

Stellingwerf, D. A. 1968
Practical applications of aerial photograph in forestry and other vegetation studies. Forests in the temperate zones forest management activities. ITC Pub. Series B, No. 46.

19 aerial photos from the Netherlands and Belgium are presented with an annotated interpretation of the forest species and other features present.

Tormar, M. S., 1973
Maslekar AR Landuse and Forest type classification proposed for Aerial photo interpretation. Indian Forester 99(5):281-295.

Discusses the need for and proposes a standard classification scheme for land use and forest type classification. Addresses the feasability of using aerial photography as an aid to classification.

Wear, J. F., R. B. Pope, P. W. Orr 1966
Aerial Photographic Techniques for estimating damage by insects in western forests. PNW 1966

Discusses aspects of data acquisition and processing including choice of film and scale, sampling design, techniques of aerial photography, and subsequent ground sampling and analysis.

Weber, Frederick P. 1965
Aerial Volume Table. J. of Forestry 63(1):25-29

Develops regression equation for predicting volume in mortality classes based on individual tree height and crown closure.

Wert, S. L. and B. Roettgering 1967
Aerial Survey of Insect-caused mortality -- Operation RECORDEX gathers data quickly, cheaply. USDA FS Research Note PSW-150

An aerial survey using an operation recorder was used to determine the extent of bark beetle damage. The method was efficient and inexpensive.

Wert, Steven L. 1969
Revised Aerial Volume Table for Estimating Spruce and Fir Mortality in Minnesota. J. of Forestry 67(5):334-336

The Weber regression equation did not have adequate precision to warrent use of the table. New equations were generated using Weber's 40 plots and 33 new plots. New revised table reflects change and indicated a better overall estimation of volume.

Willingham, J. W. 1957
Estimation of Forest Management Inventory Data from Aerial Photographic measurements. For. Sci. 3(3):270-274.

Radial Dbh, and volume were estimated from height, crown diameter, crown density, and no. of trees per acre measurements from aerial photos.

APPENDIX F

DRAFT WILLIAM USERS MANUAL

A SURVEY DESIGN PLANNING SOFTWARE PACKAGE

INTRODUCTION

PROGRAM COMPONENTS AND CONTROL STRUCTURE

INPUT REQUIREMENTS (DATA)

PROGRAM SIMLATE

PROGRAM CLUSTER

PROGRAM STRATS/ISOCLASS

PROGRAM SUMT

PROGRAM COMPARE

EXAMPLES OF USE

INTRODUCTION

This appendix provides a very rough draft of a user's manual for the WILLIAM package. It is admittedly unorganized and incomplete. Insufficient time has prevented further revision and organization.

Other additional material and documentation may be found in the working files maintained at RSRP (WILLIAM MANUAL) and the Forestry Applications Report (Colwell & Titus, 1976).

User's Guide to WILLIAM Monitor

The WILLIAM monitor allows a user to simply specify a WILLIAM module to be executed and supply module directives. The monitor, called MANA, handles all file manipulations. The normal deck setup is given below.

```
.Job card...
FETCHPS, UCFOR, MANA,MANA.
MANA.
7-8-9
(module1)/(input file)/
(module2)/
7-8-9
directives for module 1
7-8-9
directives for module 2
6-7-8-9
```

example 1 running CLUSTER & SUMT

```
.job
FETCHPS (UCFOR,MANA,MANA)
MANA.
7-8-9
CLUSTER/CLUST,24302/
SUMT/SINGLE/
7-8-9
directives for CLUSTER
7-8-9
directives for SUMT
6-7-8-9
```

in the above example the input file for CLUSTER, i.e. CLUST, was fetched from tape 24302 and SUMT(SINGL) was chosen for optimization.

The file table (see page) lists the input files needed at any step in the WILLIAM system. Note that these steps are executed in sequence, the outputs from one area inputs to the next step in the process as diagrammed. So it is sufficient to fetch the input for only the first step in a sequence.

Files may be fetched from tape or PSS. (Note) directives are expected on input unless otherwise specified! This means that a directive set may be repeated either by:

1) having occur twice on input
2) specify it twice on command line.

The module name (and option if SUMT) and any files to be fetched specified by name and location. e.g.

```
CLUSTER/CLUST, 23402/        23402 = tape#

CLUSTER/CLUST,UCFOR,EQ2BY/
```

module file file name pss library & subset

The slashes are required.

Files may be fetched from tape or PSS.

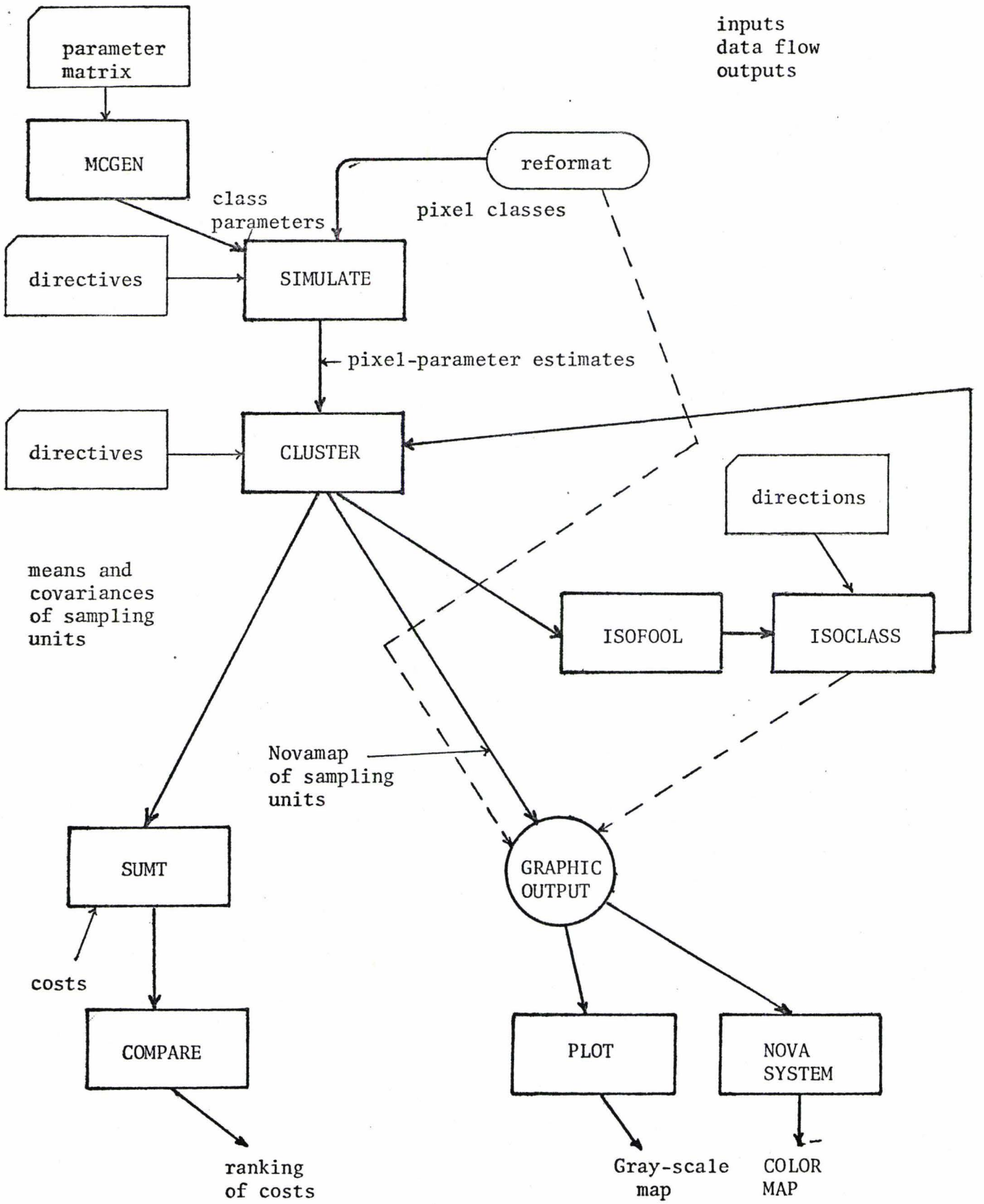
Extra control cards may be executed as needed when they are preceded by a single period.

Possible modules are:

MCGEN/
SIMLATE/
CLUSTER/
ISOFOOL/
ISOCLAS/
SUMT/SNGLE/
SUMT/DBLE/
SUMT/STRA/
PLOT/

WILLIAM

inputs
data flow
outputs



PLANNING SYSTEM WILLIAM FILE STRUCTURE

PROGRAM (binary name)	FILES (in order)	TYPE	USE
from UCFOR			
MGGEN			
(LGOGEN)	TAPE1	=	BCD card input
	SIMGEN	0	Binary output of class parameters
	OUTPUT	0	listing of SIMGEN
SIMLATE	INPUT	I	directives
(LGOSIM)	OUTPUT	0	messages
	SIMGEN	I	parameter definitions from MCGEN
	SIMAP	I	NOVAMAP input file
	CLUST	0	Binary output file for CLUSTER
CLUSTER	INPUT	I	directives
(LGOCLUS)	OUTPUT	0	messages
	CLUST	I	Binary input from cluster
	TAPE2	0/I	NOVAMAP output input from ISOCLAS*
	ISO	0/I	Binary output input to ISOFOOL
	SUMT	0	Means & covars for SUMT
	TAPE7	I	Input from ISOCLAS*
ISOFOOL	OUTPUT	0	messages
(LGOFOOL)	ISO	I	Binary input from CLUSTER
	TAPE2	X	temporary novamap (deleted at end of program)
	TAPE3	0	resultant output binary novamap for ISOCLAS
	TAPE4	X	scratch file (deleted at end of program)
	TAPE33	0	debug printout
SUMT	INPUT	I	directives
(LGOSUMT)	OUTPUT	0	messages
optional	PUNCH	0	stats
(LGOSNGL)	SUMT	I	input from CLUSTER
(LGODBLE)	TAPE2	?	unused
(LGOSTRA)	TAPE3	?	unused
	COMPAR	0	output for COMPARE

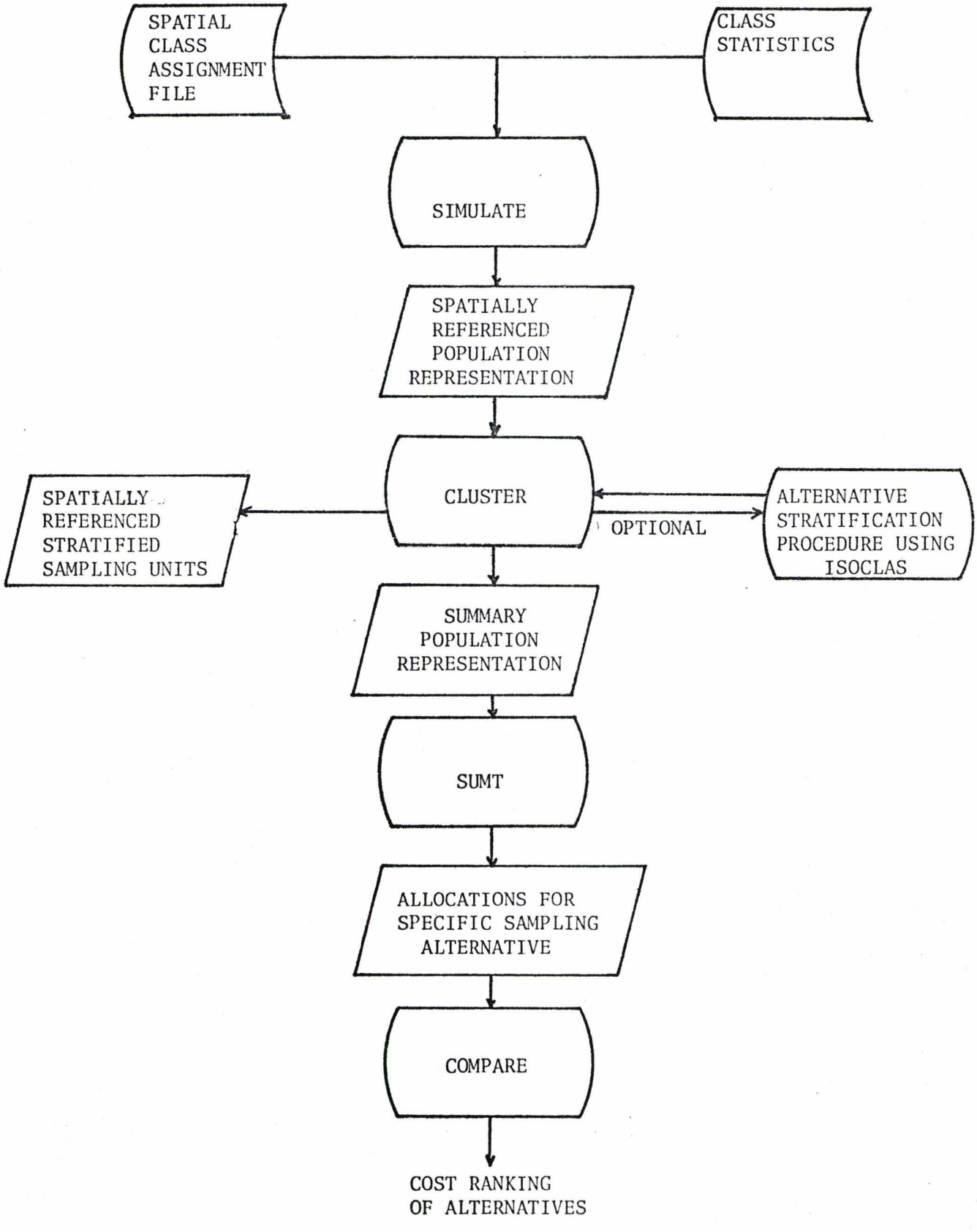
*used only on pass 2 on entry TAPE2 (ISOCLAS output file) is renamed to TAPE7

PROGRAM (binary name)	FILES (in order)	TYPE	USE
COMPAR (LGOPAR)	INPUT	I	directives
	OUTPUT	0	messages
	COMPAR	I	costs from SUMT
PLOT (LGOPLOT)	INPUT	I	directives
	OUTPUT	0	output
	TAPE2	I	NOVAMAP input from CLUSTER,ISOCLAS,
	FILM	0	GRAPHIC output file for COM
external ISOCLAS (ISOCLAS)	(not in order)		
	TAPE3	I	novamap input
	TAPE2	0	novamap output

OLD file names	NEW file names		
SIMLATE (LGUSIM)			
TAPE1 input MCGEN	SIMGEN		
TAPE2 input NOVAMAP	SIMAP		
TAPE3 bin output	CLUST		
CLUSTER LGOCLUS			
TAPE2 input SIMLATE	CLUST		
TAPE2 output NOVAMAP	TAPE2		
TAPE3 output CLUSTERS	ISO		
TAPE4 output to SUMT	SUMT		
TAPE7 input from ISOCLAS	TAPE2 in TAPE7 out		
ISOFOOL			
TAPE1 input from CLUSTER	ISO		
TAPE2 output to ISOCLASS	TAPE3		
TAPE3 debug	TAPE33		
TAPE4 scratch	- -		
ISOCLAS			
TAPE3 input	TAPE3	fixed	Programs to be added to UCFOR monitor
TAPE2 output	TAPE2		
SUMT			
TAPE1	SUMT		MCGEN (LGOGEN)
TAPE15	COMPARE		COMPLOT (LGOEOM)

WILLIAM

SOFTWARE SYSTEM COMPONENTS



SUBROUTINE STRUCTURE

SIMLATE	PROGRAMS	CLUSTER
SETUP		SETFLS
RPRINT		SETUP
MAKE		CLUS1
SUMMAR		CLUS2
		CLUS3
		CLUS4
		CLUS5
		SUMMAR
RANDOM		
DEVIATE		
VECADD		
MATMULT		
MYNSIM		
FIXUP(c)		
	UNPACK8(c)	
	REPACK(c)	
	NUMBER	
	FIND	
	REED	
	FLTNUM	
	NXTCHR	

SUMT SUBROUTINE STRUCTURE

SUMT -

BODY	CHCKER
EVAL	FEAS
OUTPUT	READIN
SET	STORE
SUMRIZE	TIMEC

BODY -

CONVRG	ESTIM
EVAL	FINAL
GRAD	OPT
OUTPUT	PEVALU
RHOCOM	TCHECK
TIMEC	XMORE

CHCKER -

PUNCH	
ABS	

DIFF1 - RESTNT

DIFF2 - GRAD1

ESTIM - EVALU, FINAL, OUTPUT, REJECT, STORE

EVAL - ALOG, RESTNT, FLOAT

FEAS - BODY, EVALU, OUTPUT, RESTNT, TIMEC

FINAL - PUNCH, SQRT, ABS

GRAD - GRAD 1, SQRT

INVERS -

OPT -

EVALU	OUTPUT
REJECT	TIMEC
ABS	

OUTPUT -

PEVALU - ALOG, FLOAT

PUNCH -

REJECT -

RHOCOM -

GRAD	INVERS
SECORD	SQRT
ABS	

SECORD -

GRAD1	MATRIX

SET -

SECOND

STORE -

TCHECK -

OUTPUT

TIMEC -

SECOND

XMOVE -

GRAD	INVERS
OPT	SECORD
SQRT	STORE

INPUT FILE FOR SIMULATE

Format 1 - binary file produced by MCGEN (NOCLS+1 records)

input to SIMULATE

Record 1 - ID record - 2 CDC words

word 1 - # classes - NOCLS
word 2 - # parameters - NPAR

Record 2 - means and covariances for class 1

NPAR + NPAR*NPAR words

words 1 to NPAR = mean1, one per parameter

next NPAR*NPAR words - covariance matrix (square)

row by row

i.e., ((COVAR(I,J), I=1,NPAR), J=1,NPAR)

Record 3 - means and covars for class 2

etc. to Record NOCLS+1

FOF

2 Nova Map tape input with a header record.

SIMULATE PROGRAM FUNCTIONS

SIMLATE - initializes and calls the major subroutines SETUP, MAKE, and SUMMAR.

SETUP - initializes, reads options cards, and verifies data as much as possible.

MAKE - reads the NOVAMAP, unpacks it and then performs the simulation using MUNSIM

SUMMAR - prints and summarizes the results of simulation.

SIMULATE PROGRAM STRUCTURE AND EXTERNALS

SIMULATE -

- SETUP
- MAKE
- SUMMAR

SETUP

- DATE (System)
- EOF (System)
- FIND
- FIXUP (Compass)
- FLTNUM
- NUMBER
- NUMBERS
- NXTCHR
- REED
- RPRINT
- SETFLS
- SUMMAR
- TIME

MAKE

- MUNSIM
- REED
- UNPACK8 (Compass)
- WARN

MVNSIM

- DEVIATE
- MATMULT
- SQRT
- VECADD

DEVIATE

- ALOG
- COS
- RANDOM
- SIN
- SQRT

(System)

FLTNUM

- SHIFT (System)

REED

- LENGTH (System)
- UNIT (System)

FIND

- SHIFT (System)

NUMBER

- SHIFT (System)

SIMULATE

format 2 - Binary output file produced by SIMULATE (Lines + 2 records) (Tape 3)

Record 2 - ID Record - 3 words

Word 1 - # old classes (from NOVAMAP)

Word 2 - # new classes

Word 3 - # params

Record 2 ID Record - variable length

Words 1 to N = names of result classes

remainder = echo NOVAMAP ID record

length = 16 + # old classes

total length = N + 16 + oldcls

Record 3 -Simulate results for line 1 (N = # params)

word 1 = NOVAMAP class +, pixel 1

2 = new class #, pixel 1

3 = simulated value for this pixel, parameter 1

4 = " " " " " " " 2

etc., 1 word per parameter for this pixel

word N + 3 = NOVAMAP class #, pixel 2

N + 4 = new class #, pixel 2

next N words = simulated values, pixel 2

etc., N + 2 words per pixel

Record 4 -SIMULATE results, line 2

etc., 4 words per line

EOF

SIMULATE control cards

none of the first 6 cards is essential - see "use" and "default" comments

order of cards is important - they should occur in the deck in the order described here. Superscripts indicate cards which are dependent on one another.

CARD FORMAT -

Columns 1 to 10 are the card identifier field and must be punched exactly as shown, beginning in col.1. If the identifier is less than 10 characters, the remaining columns of this field must be blank.

Columns 11 - 72 are the parameters field. Parameters must be separated by commas. Blanks are permitted between parameters (following, not preceeding the comma). If one card is not sufficient to provide all the information for a card, the card may be repeated (see example, NEWCLS cards). In the description below, all numbers are integer (I,J, etc.)

Ident	Params	USE	Default
NOVAMAP	Points = I, Lines = J	define size of NOVAMAP input must not exceed size of NOVAMAP provided (not implemented)	size taken from NOVAMAP Header
Classes[1]	OLD = I, NEW = J	define number of old and new classes must agree with NOVAMAP and stats file	Old taken from NOVAMAP ID, NEW taken from stats ID
PARAMS	I	define number of simulation parameter - must agree with stats	taken from stats ID
NEWCLS[1]	Name, I = A,B,C...	Define new class called NAME, whose # in the stats file is I, to be composed of old classes, A,B,C...	see below

Note on 'NEWCLS card illegal if CLASSES card was not included initially, the program maps all old classes to zero. If no NEWCLS card appears, all old classes are mapped to new classes one-to-one. If any NEWCLS card appears, only the old classes specified will be mapped - all others will remain null.

Ident	Param	USE	Default
EMPTY[1]	I,J,K	Define new classes which should not occur this is probably superfluous, since such a class could not be defined on a NEWCLS card. Note that stats must still be provided, even if just a set of zeros.	
IGNORE[2]	I,J,K,	define new classes that should be mapped to zero, i.e. not simulated	all new classes defined on NEWCLS cards, will be simulated 0.3789
SEED	X. Y	Read number to set seed for Random Number Generator	
*END	(none)	optional - do nothing - just for compatability with CALSCAN	
$END	(none)	end of car input - read ID records and verify	required
$EXIT	(none)	stop processing - use this card to terminate job if you wish merely to check your deck and data for correctness. Program will read and check all cards, read ID records from NOVAMAP + stats, and print a summary of the optional selected.	

Ident	Param	USE	Default
$GO	(none)	process data - use this instead of $EXIT if you wish to simulate	no processing

The program will always attempt to read the entire deck, even if it detects errors. An offending card will produce an error message and a flag will be set so that processing does not occur (just as if $EXIT had been used - this does not mean $EXIT is unnecessary - there are errors the program cannot detect - you should always verify its interpretation of your cards).

CLUSTER PROGRAM FUNCTIONS

CLUSTER - supervises iterations and calls the major subroutines SETUP, CLUSI, and SUMMAR.

SETUP - reads control and option cards, sets default values, initializes, and reads and writes appropriate header records.

CLUS1 - supervises the clustering and computation of variance as well as the default stratification process (maximum of 15 strata until SUMT is expanded to handle more Phase 15 strata).
Calls CLUS2 to accumulate values by line of input data.
Calls CLUS3 to complete calculations for each result line and complete variance computation.
Calls CLUS4 to accumulate overall statistics between clusters.
Calls CLUS5 to complete the computations of statistics.

SUMMAR - prints the results of clustering including counts of input pixels & result pixels by class, means, covariance matrix, and average covariance matrix.

CLUSTER PROGRAM STRUCTURE AND EXTERNALS

CLUSTER (Main)

- SETUP
- CLUS1
- SUMMAR
- WARN (System)

SETUP

- ABORT (System)
- EOF (System)
- FIND
- FLTNUM
- NUMBER
- NUMBERS
- NXTCHR
- REED
- SETFLS

CLUS1

- CLUS2
- CLUS3
- CLUS4
- CLUS5
- EOF (System)
- REED
- REPACK (Compass)
- UNPACK8 (Compass)
- WARN (System)

CLUS3

- AMAX1
- MOD in live function
- SHIFT

FIND

- SHIFT (in live function)

FLTNUM

- SHIFT (in live function)

NUMBER

- SHIFT (in live function)

Cluster Data Cards

Required cards are CYCLES, $END, and $EXIT. CYCLES must be the first card, followed by options cards in any sequence. $GO card if used must follow $END.

IDENT	PARAMS	USE	DEFAULT
CYCLES	NREPS	specify the number of iteration desired. NREPS sets of cluster data cards must follow each terminated by $EXIT	None
CLUSTER	X=I, Y = J	I and J integers specifying the dimensions of clusters both GE. 2 and LE.200	X=4, Y = 4
IGNORE	A,B,C	Classes to be ignored in constructing selection probability and determining status for each cluster Some classes may have to be ignored as 15 classes is the maximum cluster will handle.	No classes ignored
PRINT	N	N = 0, minimal printing N = 1, print by result lines N = 2, detailed debug printing	0
SAVE	blank	Presence of this card causes intermediate file (tape 3) to be written	no file written
USE	K	K=1, for PASS.Eq. 1 in alternative stratification procedure if K=1, SAVE must be used. K=2, for PASS 2 in alternative stratification procedure if K=2, SAVE must <u>not</u> be used	(No USE card) stratification procedure
$END	blank	Signals end of option cards this card is <u>required</u>. Prints option then continues.	Required

IDENT	PARAMS	USE	DEFAULT
$GO	blank	presence of this card proceed if no errors must follow $END	no clustering only check control cards
$EXIT	blank	return control to CLUSTER required must be the last card of seuquence for each itereturn	

Format 3 - CLUSTER result file (Tape 3) - NLINS + 2 records
OPTIONAL - triggered by SAVE card

Record 1 - ID record - 6 words

word 1 = # parameters (NOPARS)

2 = # point per line after clustering (NPB)

3 = # lines after clustering (NLINS)

4 = # cluster (NOCLS)

5 = X - dimension of a cluster (XCLUS)

6 = Y - dimension of a cluster (YCLUS)

Record 2 - ID record - NOCLS + 2 words

word 1 = # classes

words 2 to end = Names of classes

Record 3 - 1st data record, clustered line #1

Length = NPTS + NPTS + (NOPARS*NPB)

+ NPTS*(NOPARS*(NOPARS*NPB)

+ NPTS words

First NPTS words - class assigned to each cluster

next NPTS words - number of valid pts in each cluster

next (NOPARS*NPTS) words - p-totals for each cluster

next NPTS*((NOPARS*(NOPARS+1))/2 words -

lower triangular covar matrix for each pt.

(order of elements = ((CVAR(I,J), I=J, NOPARS)

next NPTS words - packed data about "best" 4 classes in each cluster

Record 4 = clustered data for result line 2

etc.

EOF

Format 4 - CLUSTER result file (Type 4) - 3 records provided automatically

Record 1 - ID record - 4 words

word 1 = # classes (NOCLS)

2 = # param (NOPARS)

3 = IX

4 = IY

Record 2 - ID record - NOCLS words

Names of classes

Record 3 - Summary of clustering by class.

length = (NOPARS+2*(NOPARS*(NOPARS+1)/2 + 1)*NOCLS words

1

First NOPARS*NOCLS words = means for parameters for each class

((MEANS(I,J), I=1, NOPARS), J=2, NOCLS)

next (NOPARS*(NOPARS+1)/2)*NOCLS words = lower triangular matrices

laves triangular COVAR matrices for classes

((CVAR(I,J,K), I =J,NOPARS), J= 1,NOPARS),K = 1, NOCLS)

next NOCLS words - number of clusters in each class

(TOTALS(I), I = 1, NOCLS)

EOF

Data available from CLUSTER OUTPUT FILE unit 2 - (Binary -)

Provided automatically

NOVAMAP of clustered data which gives stratification class of each cluster with header

Record 1 - NPTS,NLINS,NOLLS,(NAMES(I),I=1,NOCLS)

Record 2 - (DAT(I),J=NVBAS,NVTOP)
which translates to Packed Novamap for line 1 with NPTS values.
Packed by REPACK in 8 bit bytes.

Record 3 - Record NUNS+1 as per record 2

Note - Unit 2 will not be written if PASS.EQ.2 since a NOVAMAP is input from unit 7 in that case.

Data available from CLUSTER OUTPUT FILE 4 (Binary)

Record 3
((AMEAN(I,J),I=1,NPAR),J=1,NCLS),
((COV(I,J),I=1,NSIZE),J=NCLS),
((ACOV(I,J),I=1N,NSIZE),J=1,NCLS),
NSIZE=NPAR*(NPAR+1)/2
(COUNT(J),J=1,NCLS)

Record 2 (NAME(J),J=1,NCLS)

Record 1 NCLS,NPAR,IX,IY

Data available from CLUSTER OUTPUT FILE 3 (Binary)

Record 1 NPAR,NPTS,NLINS,NCLS,IX,IY

Record 2 NCLS,(NAMES(J),J=1,NCLS)

Record 3 data record for line 1:
(ICCLASS(J),J=1,NPTS),
(PGOOD(J),J=1,NPTS),
((PTOTS(I,J),I=1,NPAR),J=1,NPTS),
(((CVAR(I,K,J),K=I,NPAR),J=1,NPTS),
(PAKDATA(J),J=1,NPTS)

Record 4 data record for line 2 as per Record 3

.
.
.

Record NLINS+2 data record for line NLINS

Program CLUSTER

ISOCLASS

1) PASS 1 through Cluster - CAUTION the tape 3 output file generated by SAVE will be quite large if cluster size is small. It may require a mag tape for storage. See description of output TAPE3 for more info. on likely size.

control cards:

USE 1

SAVE

system cards:

LIBRITE,UCFOR,TAPE3,XXXX,308,MERRITT.

CATALOG,TAPE3,CLUST3. (in case file too big for PSS

FETCHMT,TAPE1,NT,TAPE#).

Cluster size for ISOCLAS must be such that NLINS≥ 12 NPTS≥12 See output for unit 3

Cluster card not necessary

2) PASS 2 through Cluster

control cards:

USE 2

SAVE card must NOT be present in this run since File 3 is now a READ file

system cards:

FETCHPS,UCFOR,TAPE3,XXXX (previous cluster output TAPE3)

FETCHPS,UCFOR,TAPE7,ISOFILE. (ISOCLAS Result NOVAMAP file)

Not necessary to have available TAPE1 (the SIMULATE RESULT TAPE FILE)

*Both EQL and PPS result files can be generated from the same PASS 1 and ISOCLAS files.

For the ISOCLASS stratification, consult the ISOCLASS user's manual available from RSRP, Berkeley for guidance on preparation of ISOCLASS directives.

SUMT CONTROL DIRECTIVES

The following pages summarize the control card structure for the SUMT component. The cards consist of two types, those required by the general SUMT algorithm (Mylander et al, 1971) and those required by the particular problem being executed in the model. These depend on the subsampling method to be used (STRAT = STRAT, STRAT2S = SNGL, STR2SD = DBLE).

SUMT CONTROL DIRECTIVES

Card Order	Columns	Format	Variable Name	USE	Usual Value
1				PARAMETER CARD	.01
	01-12	E12.0	EPSI	Tolerance used to decide if an unconstrained minimum has been achieved for each subproblem. (See option 9)	
	13-24	E12.0	RHOIN	Possible initial value of r. (See option 1)	1.
	25-36	E12.0	THETAØ	Tolerance used to decide if the solution to the NLP problem (A) has been approximated (See option 5)	.001
	37-48	E12.0	RATIO	Parameter (>1) used to compute consecutive values of r; $r_{i+1} = r_i/c$.	16.
	49-60	E12.0	TMMAX	Max. amount of time for solving problem (in sec.)	20.
	61-64	I4	M	Integer number of nontrivial constraints, where (m+mz) $\leq$ 200. (See option 2)	
	65-68	I4	N	Integer number of variables, N $\leq$ 100.	
	69-72	I4	MZ	Integer number of equality constraints, where (m+mz) $\leq$ 200.	0.
2				INITIAL STARTING POINT VECTOR	
	1-72	6E12.0	XØ(I)	I = 1, N. Since there are 6 components/card, the XØ(I) vector requires (N/6) cards	(N/6) blank cards
3				FIRST CARD READ BY SUBROUTINE READIN	
	1-10	10X		IOHREADIN .	
	11-17	A7	TEST	7HPRINTON	
	18-20	3X		3H,T =	
	21-30	F10.0	T	Controls the sigma distribution. DOUBLE SAMPLING ONLY	1.0

Card Order	Columns	Format	Variable Name	USE	Usual Value
	31-35	5X		5Hb RHO =	
	36-40	F5.4	RHO	Correlation coefficient for double sampling option.	.8
4				SECOND CARD READ BY SUBROUTINE READIN	
	1-50	10F5.0	COST(I)	I = 1, 3 in SINGLE sampling. I = 1, 5 in DOUBLE sampling. Coefficients of the objective function.	User Specified
5				THIRD CARD READ BY SUBROUTINE READIN	
	1-50	10F5.0	AERR(I)	I = 1, NPAR (NPAR = 3 is defined on Tape 1). Max. allowable error for estimates.	User Specified
6				OPTION CARD	
	1-7	I7	NT I	Option # 1	2
			= 1	The value for r is made by finding an approximation solution min $\{[\nabla P(x^o,r)[\nabla^2 P(x^o,r)]^{-1}\nabla P(x^o,r]\}$ which is a good approximation only when x^o is close to the boundary (i.e. for some i, $g_i(x)$ is close to zero) or when $\nabla^2 f(x^o) = 0$ and when MZ = 0.	
			= 2	r_i is given by formula 8.65 [Ref. 1, pg. 191] (Only can be used when MZ = 0).	
			= 3	r_i = RHOIN (See parameter card)	
	8-14	I7	NT 2	Option # 2	1
			= 1	The requirements (trivial constraints) that $x_i \geq 0$ for i = 1, n are to be automatically included in the problem.	
			= 2	The only constraints on the problem are those input by the user.	

SUMT CONTROL DIRECTIVES

Card Order	Columns	Format	Variable Name	USE	Usual Value
1				PARAMETER CARD	.01
	01-12	E12.0	EPSI	Tolerance used to decide if an unconstrained minimum has been achieved for each subproblem. (See option 9)	
	13-24	E12.0	RHOIN	Possible initial value of r. (See option 1)	1.
	25-36	E12.0	THETAØ	Tolerance used to decide if the solution to the NLP problem (A) has been approximated (See option 5)	.001
	37-48	E12.0	RATIO	Parameter (>1) used to compute consecutive values of r; $r_{i+1} = r_i/c$.	16.
	49-60	E12.0	TMMAX	Max. amount of time for solving problem (in sec.)	20.
	61-64	I4	M	Integer number of nontrivial constraints, where (m+mz) $\leq$ 200. (See option 2)	
	65-68	I4	N	Integer number of variables, N $\leq$ 100.	
	69-72	I4	MZ	Integer number of equality constraints, where (m+mz) $\leq$ 200.	0.
2				INITIAL STARTING POINT VECTOR	
	1-72	6E12.0	XØ(I)	I = 1, N. Since there are 6 components/card, the XØ(I) vector requires (N/6) cards	(N/6) blank cards
3				FIRST CARD READ BY SUBROUTINE READIN	
	1-10	10X		IOHREADIN .	
	11-17	A7	TEST	7HPRINTON	
	18-20	3X		3H,T =	
	21-30	F10.0	T	Controls the sigma distribution. DOUBLE SAMPLING ONLY	1.0

Card Order	Columns	Format	Variable Name	USE	Usual Value
	31-35	5X		5Hb RHO =	
	36-40	F5.4	RHO	Correlation coefficient for double sampling option.	.8
4				SECOND CARD READ BY SUBROUTINE READIN	
	1-50	10F5.0	COST(I)	I = 1, 3 in SINGLE sampling. I = 1, 5 in DOUBLE sampling. Coefficients of the objective function.	User Specified
5				THIRD CARD READ BY SUBROUTINE READIN	
	1-50	10F5.0	AERR(I)	I = 1, NPAR (NPAR = 3 is defined on Tape 1). Max. allowable error for estimates.	User Specified
6				OPTION CARD	
	1-7	I7	NT I	Option # 1	2
			= 1	The value for r is made by finding an approximation solution min $\{[\nabla P(x^o,r)[\nabla^2 P(x^o,r)]^{-1}\nabla P(x^o,r]\}$ which is a good approximation only when x^o is close to the boundary (i.e. for some i, $g_i(x)$ is close to zero) or when $\nabla^2 f(x^o) = 0$ and when MZ = 0.	
			= 2	r_i is given by formula 8.65 [Ref. 1, pg. 191] (Only can be used when MZ = 0).	
			= 3	r_i = RHOIN (See parameter card)	
	8-14	I7	NT 2	Option # 2	1
			= 1	The requirements (trivial constraints) that $x_i \geq 0$ for i = 1, n are to be automatically included in the problem.	
			= 2	The only constraints on the problem are those input by the user.	

Card Order	Columns	Format	Variable Name	USE	Usual Value
	15-21	Iy	NT3	Option # 3	1
			= 1	Standard printout (this includes a call to OUTPUT after the solution of every subproblem. Also the "Lagrange multipliers" and the first-and second-order solution estimates are printed.)	
			= 2	For additional printout (includes standard printout and every intermediate points, gradient of P and the vector of S.)	
	22-28	I7	NT4	Option # 4	1
			= 1	Final convergence is determined on the basis of current solution to the subproblem.	
			= 2	Final convergence is determined on the basis of the first order estimates. The first order estimate of the solution vector must be close to feasible. See below.	
			= 3	Final convergence is determined on the basis of the second order estimates. The second order estimate of the solution vector must be close to feasible before the convergence check is made. If $\bar{x}$ is a solution estimate it is considered close to being feasible if $g_i(\bar{x}) + 0_0 > i=1,m$, where θ_0 is defined on the parameter card.	
	29-35	I7	NT5	Option # 5 The covergence criterion determining the NLP problem has been solved. (Only use = 1 when NT4 $\neq$ 1)	1 (See ref. 1, pg. 195)

Card Order	Columns	Format	Variable Name	USE	Usual Value
			= 1	Quit when $\left\| \frac{G - f[x(r_k)]}{G[x(r_k), \mu(r_k), \lambda(r_k)]} - 1. \right\| < \theta_0$	
			= 2	Quit when $\left\| r \Sigma_{j=1}^{m} \ln g_j . [x(r_k)] \right\| < \theta_0$	
			= 3	Quit when $\left\| \frac{\text{first order estimate of } v_o}{G[x(r_k), \mu(r_k), \lambda(r_k)]} - 1. \right\| < \theta_0$	
	36-42	I7	NT6	Option # 6	1
			= 1	After final convergence the program reads in new data and solves the next problem.	
			= 2	After final convergence has been determined a call to PUNCH is made before proceeding on to the next problem.	
	43-49	I7	NT7	Option # 7 First move after a minimum to a subproblem is achieved.	1
			= 1	No extrapolation.	
			= 2	Extrapolate through last two minima.	
			= 3	Extrapolate through last three minima.	
	50-56	I7	NT8	Option # 8 Not used	blank
	57-63	I7	NT9	Option # 9 Subproblem convergence criterion, or when to stop minimizing P function for fixed value of r (see parameter card)	1

Card Order	Columns	Format	Variable Name	USE	Usual Value
			= 1	Quit when $\left\| \nabla_x p^T (x^i,r) \left[\frac{\partial^2 P(x,r)}{\partial x_i \partial x_j} \right]^{-1} \nabla_x P(x^i,r) \right\| < \varepsilon$	
			= 2	Quit when $\left\| \nabla_x p^T (x^i,r) \left[\frac{\partial^2 P(x,r)}{\partial x_i \partial x_j} \right]^{-1} \nabla_x P(x^i,r) \right\| < \frac{P(x^{i-1}) - P(x^i)}{5}$	
			= 3	Quit when $\left\| \nabla_x P(x_i,r) \right\| < \varepsilon$	
	64-67	I7	NT10	Option # 10	1
			= 1	At least one nonlinear constraint.	
			= 2	Linear constraints. User supplied Subroutine MATRIX will be called only to get the second partials of f(x).	
			= 3	Linear constraints and linear objective function (i.e., a linear programming problem). The user supplied Subroutine MATRIX will not be called.	
7	01-12	E12.6	XEP1	TOLERANCE CARD If some first or second derivatives are to be gotten by numerical differencing (see Second Option Card following) this is the value used to compute them. See the description of DIFF1. (Usually setting XEP1 = .0001 is satisfactory although a good value is dependent on the scaling of the problem).	.0001

Card Order	Columns	Format	Variable Name	USE	Usual Value
	13-24	E12.6	XEP2	When minimizing the P-function for a given value of r(RHO) the value of P must decrease by an amount exceeding XEXP2 for each iteration after the first. If it does not, then the code prints out the message "apparently roundoff errors prevent a more accurate determination of the minimum of this subproblem", and it is assumed a minimum has been found. (Usually XEP2=0).	10^{-8} Sngl. Model 10^{-4} Dble. Model
8				SECOND OPTION CARD	
	1-7	I7	NEXOPI		1
			= 1	Solve problem without checking derivatives.	
			= 2	Solve problem after checking only first derivatives.	
			= 3	Do not solve problem after checking only first derivatives.	
			= 4	Solve problem after checking first and second derivatives.	
			= 5	Do not solve problem after checking first and second derivatives.	
	8-14	I7	NEXOP2		1
			= 1	The method for minimizing the unconstrained penalty function is to be the generalized Newton-Raphson method as modified to handle indefinite Hessian matrices. This method requires functions values, first, and second derivatives.	

Card Order	Columns	Format	Variable Name	USE	Usual Value
			= 2	Same as 1, except that when an "orthogonal move" is made because of an indefinite Hessian matrix $\leq \nabla P$ is added to the orthogonal move vector.	
			= 3	Steepest descent is used to minimize P-function.	
			= 4	The method for minimizing the unconstrained penalty function is McCormick's modification of the Fletcher Powell method as reported in the Fiacco-McCormick book. This requires function values and first derivatives.	

APPENDIX G

FILES STRUCTURE FOR WILLIAM AND GRAY'S HARBOR STUDY

In implementing and modifying the planning model a number of data and program files were generated. This appendix provides a listing of files generated on the Lawrence Berkeley Laboratory Computer Center PSS library for permanent files. A second list is provided for magnetic tape files which were too large for the permanent file space. The PSS library name is UCFOR, owner is Merritt and Group is 308. Data files are identified in the following codings:

IEQL2X	- ISOCLASS stratification, EQUAL selection probability. 2 x 2 cluster size
WEQL2X	- Default stratification others as above
IPPS2X	- ISOCLASS stratification, proportional-to-size selection probability
WPPS2X	- Default stratification, others as above

other data files are of a similar form

All PSS files will be copied to magnetic tape to provide duplicate files.

Program source and object codes are included for all components of WILLIAM. Source code files are in the CDC UPDATE format. Object code files are of the LGO type.

The following files are particularly important:

FILE	DESCRIPTION
MANASC	Monitor program source code
MANA	Monitor program object code
SIMPL	SIMULATE source code (UPDATE PL)
CLUSPL	CLUSTER source code (UPDATE PL)
LGOSUMT	SUMT OBJECT CODE
LGOSNGL	STRAT2S/ SUMT OBJECT CODE
LGODBLE	STR2SD/ SUMT OBJECT CODE
USFSDAT	Class statistics for SIMULATE
SUMTPL	SUMT Source Code (UPDATE PL)
SNGLPL	STRAT2S Source Code (UPDATE PL)
DBLEPL	STR2SD Source Code (UPDATE PL)
STRATPL	STRAT Source Code (UPDATE PL)

FILE	DESCRIPTION
FOOLSPL	ISOFOOL Source Code (UPDATE PL)
'LGOFOOL	ISOFOOL Object Code
LGOSIM	SIMULATE Object Code
'LGOCLUS	CLUSTER Object Code
MCGENSC	MCGEN Source Code (operates on USFS DAT prior to SIMULATE)

Magnetic tape files were maintained for large files. They are all self explanatory and will be maintained by the Remote Sensing Research Program at Space Sciences Laboratory, UC Berkeley.

MAGNETIC TAPE FILES

SSL #	LBL#	Tracks, BPI	Type	Contents
139		NT, D8	RAW ERTS	Gray's Harbor lines 1-700, PTS 1-810
169	22798	NT, D8	NOVAMAP	Gray's Harbor 53 classes 1-700, 1-810
171		NT, D8	NOVAMAP	Gray's Harbor with Fake Header 1-699, 1-810
245		NT, D8	NOVAMAP	Gray's Harbor Clustered 10 x 10, 1-70, 1-81
260		NT, D8	NOVAMAP	Gray's Harbor Clustered 3 x 3, 1-233, 1-270
313	23456	NT, D8	NOVAMAP	ISOCLASS 10 x 10 1-70, 1-81
314		NT, D8	RAW ERTS	ESL - ENTIRE SCENE 18272
315		NT, D8	NOVAMAP	ELS - ENTIRE SCENE 18272
	23402	NT, D9	SIMULATE	SIMULATE RESULT FILE FOR INPUT TO CLUSTER

PSS LIBRARY UCFOR PSSLIST V9B/BKY67A 06/06/77 PAGE 1
16.35.10

PSS LIBRARY UCFOR IT RESIDES ON DATA CELL 5
WAS CREATED ON - 02/26/77
WAS LAST CHANGED ON - 06/02/77 < 190 CHANGES SINCE CREATION>
WAS LAST READ ON - 06/04/77 < 3 READS SINCE LAST CHANGE>

SUBSET NAME	DATE LAST CHANGED	NUMBER OF PRU	PSS ADDRESS...
MANASC	4/07/77	2	00000010020502420074
MANA	2/27/77	4	00000020060502420076
SIMLATE	5/12/77	1	00000004070502420102
CLUSTER	5/12/77	1	00000004100502420103
SUMI	2/27/77	1	00000004110502420104
SIMPL	5/05/77	32	00004054010502450105
CLUSPL	5/15/77	26	00002114070531760025
LGDSUMT	5/12/77	31	00002064220511510103
LGDSNGL	5/09/77	7	00002010050505450022
LGDABLE	5/09/77	8	00000040150504300005
USESDAT	3/14/77	9	00002034020504360015
BINPCGE	5/05/77	1	00000004030512550076
SUMIPL	5/11/77	31	00002104160512550077
SNGLPL	5/09/77	5	00000024230512550136
DBLEPL	5/09/77	7	00002004060512550143
EGL1 X	3/27/77	3	00000014110532140032
SIMBIN	3/20/77	55	00006054040532140035
SIRATPL	5/09/77	5	00000024110536750004
LGDSTRA	5/09/77	7	00000034200536750011
WEPS2X	4/03/77	3	00000014230536750020
WEPS3X	4/03/77	3	00002004020536750023
WEPS4X	4/03/77	3	00000014050526110002
WEPS1 X	4/03/77	3	00000014100526110005
WEPS25X	4/03/77	3	00000014130526110010
WEPS5 X	4/03/77	3	00000014160526110013
WEPS75X	4/03/77	3	00000014210526110016
WEQL2X	4/03/77	4	00002014010526110021
WEQL3X	4/03/77	3	00000014040532370121
WEQL4X	4/03/77	3	00000014070532370124
WEQL1 X	4/03/77	3	00000014120532370127
WEQL25X	4/03/77	3	00000014150532370132
WEQL5 X	4/03/77	3	00000014200532370135
WEQL75X	4/03/77	3	00000014230532370140
ISO	4/21/77	147	00020004060532370143
ISOPIR	4/30/77	2	00000010100545020056
ISOMAP	5/03/77	71	00006060230545020060
IPQL1 X	5/09/77	3	00002004020540740117
PLOI	4/23/77	2	00000010040522050122
PLOLSPL	5/18/77	32	00002100200522050124
LGOPOOL	5/18/77	29	00004020050530600070

PSS LIBRARY UCFOR PSSLIST V9R/BKY67A 06/06/77 PAGE 2
16.35.10

SUBSET NAME	DATE LAST CHANGED	NUMBER OF PRU	PSS ADDRESS...
LIB	4/26/77	8	00000040150516250125
IHPS5 X	5/09/77	3	00000014200516250135
IEQL5 X	5/10/77	3	00000014230516250140
IEQL25X	5/10/77	3	00002004020516250143
IEQL65X	5/10/77	3	00000014050520630002
IHPS65X	5/11/77	3	00000014100520630005
IHPS25X	5/11/77	3	00000014130520630010
CALCTST	5/11/77	8	00000040230520630013
IHPS1 X	5/11/77	3	00002004020520630023
CALCNEW	5/12/77	6	00000030100512120076
LGOSIM	5/12/77	23	00002060130512120104
LGOLLUS	5/31/77	34	00004044050535640133
MLGENSC	5/12/77	1	00000004060506310125
MLGEN	5/12/77	1	00000004070506310126
LGOGEN	5/12/77	1	00000004100506310127
IHPS 4X	5/15/77	3	00000014130506310130
IEQL 4X	5/15/77	3	00000014160506310133
PLOTCOM	5/22/77	4	00000020220506310136
CALCNW2	5/31/77	4	00002010020506310142
IHPS 2X	6/01/77	5	00000024070505610076
IHPS 3X	6/02/77	3	00000014120505610103
IEQL 3X	6/02/77	3	00000014150505610106
-- SUBSET TABLE --		1	00000004160505610111
		-----	(ALOPTR=03704)
PHYSICAL RECORD UNITS---		694	(35 ALLOCATION UNITS)

APPENDIX H

Summary of WILLIAM Results for Gray's Harbor Test Site

This appendix summarizes the results of execution of the Planning Model for the Gray's Harbor test site. The tables are self-explanatory and are organized as follows:

Table		
H - 1	Cost Data Set 1	AE = (.05 .05 .05)
2		
3		
4		AE = (.05 .15 .15)
5		
6		
7		
8		AE = (.10 .20 .20)
9		
10	Cost Data Set 2	AE = (.05 .05 .05)
11		
12		
13		AE = (.05 .15 .15)
14		
15		
16		
17		AE = (.10 .20 .20)
18		
19	Sensitivity to allowable error (AE)	
20	Sensitivity to correlation	

In groups of 4 tables, for example, H-1 to H-4, AE = (.05 .05 .05), tables H-1 and H-2 are for the default stratification procedure and H-3 and H-4 are for the ISOCLASS stratification. Each pair of tables are given, one for proportional-to-size selection probability and the other for equal selection probability. Tables H-9 and H-18 are for proportional-to-size selection probability.

Table H-1 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00, \alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Number of Sample Units		
	STRAT F	STRAT2S F	STR2SD F	STRAT Σn*	STRAT2S Σn* Σn'	STR2SD Σn* Σn' Σn
2x2	227,344			532.9		
3x3	203,433			242.1		
4x4	193,231	195,982		138.1	137.4 2197.9	
10x10	208,806	191,187	73,188	27.3	54.2 2378.7	105.2 3540.6 105.6
25x25		283,413	71,020		58.9 2373.3	101.9 3513.3 102.1
50x50		188,908	69,295		55.4 2373.8	98.6 3484.1 99.2
75x75		185,163	66,066		53.9 2329.7	91.2 3533.3 96.7

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-2 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00, \alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Number of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	230,267			545.3		
3x3	208,442			248.4		
4x4	201,657	204,014		144.4	146.8 2278.8	
10x10	233,512	204,505	75,554		77.2 2471.5	109.7 3673.7 109.9
25x25		212,019	75,587		114.8 2521.7	111.3 3775.1 111.4
50x50		216,024	81,476		191.1 2457.9	126.9 4157.9 127.8
75x75		199,555	77,097		103.8 2405.6	107.0 4363.8 115.7

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-3 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2						
3x3						
4x4						
10x10		143,796	106,955	30.7 1625.7	142.0 3823.2	142.6
25x25		202,537	78,614	76.4 2426.1	112.7 3638.1	113.9
50x50		189,040	68,387	54.4 2374.7	99.8 3513.1	99.9
65x65		191,335	74,324	58.0 2358.7	107.9 3594.7	108.3

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-4 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) t = 1.00, α = .67
2.) AE = (.05, .05, .05)
3.) Cost Data Set 1
4.) ρ = .8

MODEL VARIABLES

1.) Isoclas Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2						
3x3						
4x4						
10x10	209,670	146,343	107,840	26.0	31.0 1660.0	143.5 3873.6 143.9
25x25		205,723	79,405		83.7 2451.7	115.2 3680.3 115.4
50x50		195,770	69,623		65.5 2416.4	102.0 3585.7 102.1
65x65		193,368	74,960		64.4 2370.6	109.4 3631.5 109.5

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
n* - sum of sample sizes over all strata for primary sample units
n' - sum of sample sizes over all strata for secondary sample units
n - sum of sample sizes over all strata for tertiary sample units

Table H-5 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	42,908	44,099		59.7	59.6 238.5	
3x3	35,964	36,290		27.9	28.2 246.0	
4x4	37,740	36,302		19.6	23.1 270.8	
10x10	108,565	38,165	29,586	13.6	28.3 279.3	35.7 534.3 35.7
25x25		38,539	29,219		29.5 280.3	34.3 527.5 35.7
50x50		37,521	28,557		26.7 276.3	32.3 510.8 34.7
75x75		34,178	25,268		21.9 270.3	29.5 501.4 31.0

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-6. Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00, \alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2	43,368			60.3		
3x3	38,348			30.3		
4x4	42,166			22.6		
10x10	123,994	41,884	30,935	15.7	35.9 306.0	38.3 581.7 38.4
25x25		44,803	32,208		47.4 315.1	41.9 622.4 42.0
50x50		49,357	36,588		71.0 321.7	53.4 738.5 54.1
75x75		42,670	32,052		55.7 289.3	46.8 703.4 46.9

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-7 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2						
3x3						
4x4						
10x10		44,893	50,872	26.0 239.9		52.4 577.1 55.3
25x25		34,656	32,138	14.7 273.8		34.1 549.1 37.4
50x50		32,399	25,612	16.7 272.1		29.8 513.8 30.9
65x65		33,088	29,103	13.6 276.0		33.0 546.3 34.2

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-8. Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2						
3x3						
4x4						
10x10		44,973	50,952		26.0 241.1	52.6 580.2 55.5
25x25		34,900	32,207		14.8 276.9	34.2 551.8 37.5
50x50		33,671	25,964		18.3 282.6	31.3 526.3 31.4
65x65		33,798	29,164		14.6 279.0	33.1 548.9 34.3

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-9. Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.10, .20, .20)
3.) Cost Data Set 1
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2	29,672			34.1		
3x3	25,658			17.2		
4x4	27,225			12.7		
10x10	96,731	23,072	24,441	12.0	12.0 144.3	25.7 314.5 27.2
25x25		23,343	24,266		12.0 148.2	23.9 310.7 27.3
50x50		23,424	24,129		12.0 149.3	23.7 307.9 27.1
75x75		21,328	21,236		10.1 150.3	21.9 310.5 24.1

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-10 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	383,000			531.9		
3x3	388,711			239.9		
4x4	395,441	393,794		137.3	196.8 2165.9	
10x10	490,796	410,546	49,130	27.3	266.6 2251.2	108.8 3389.1 108.9
25x25		413,576	48,161		255.9 2269.2	104.6 3380.8 105.2
50x50		411,659	47,233		219.6 2262.6	100.2 3364.7 101.9
75x75		411,163	46,732		100.1 2273.1	90.2 3420.6 100.0

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-11 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	388,499			539.6		
3x3	399,016			246.3		
4x4	413,815	403,704		143.7	256.1 2214.3	
10x10	552,042	421,000	51,060		353.2 2299.6	113.4 3514.1 113.4
25x25		430,060	52,125		453.8 2338.8	114.1 3636.1 114.5
50x50		437,793	58,465		234.9 2406.1	127.6 4054.9 129.6
75x75		434,984	56,741		104.2 2405.0	107.7 4198.5 120.3

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-12 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2						
3x3						
4x4						
10x10		289,005	59,653	77.6 1597.0		148.9 3506.9 150.1
25x25		416,071	51,816	349.8 2272.6		116.2 3490.5 117.7
50x50		411,455	47,700	211.6 2262.3		102.6 3391.2 102.8
65x65		410,776	50,226	137.9 2266.8		110.4 3459.9 111.8

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-13 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .05, .05)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT F	STRAT2S F	STR2SD F	STRAT Σn*	STRAT2S Σn* Σn'	STR2SD Σn* Σn' Σn
2x2						
3x3						
4x4						
10x10	468,222	293,046	60,322	26.0	88.2 1618.2	151.3 3550.2 151.4
25x25		418,900	52,485		379.4 2285.1	118.3 3532.2 119.1
50x50		415,194	48,704		232.8 2280.8	104.9 3458.1 105.1
65x65		412,373	50,791		142.5 2275.1	112.5 3495.5 113.0

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-14 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) t = 1.00, α = .67
2.) AE = (.05, .15, .15)
3.) Cost Data Set 2
4.) ρ = .8

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	42,750	43,808		59.4	61.2 236.6	
3x3	45,100	43,812		27.8	36.9 239.3	
4x4	56,364	44,553		19.6	44.9 242.5	
10x10	244,460	46,001	12,025	13.6	50.5 250.0	36.7 458.9 37.6
25x25		46,495	11,901		48.4 252.9	34.7 461.1 37.4
50x50		46,620	11,512		39.2 254.6	32.9 449.2 36.2
75x75		46,856	10,605		30.9 256.9	29.9 441.5 32.5

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-15 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2	43,343			60.2		
3x3	48,976			30.2		
4x4	65,168			22.6		
10x10	281,929	47,423	12,970	15.7	74.9 255.1	40.1 500.2 40.2
25x25		49,094	14,111		100.1 261.6	43.4 549.7 43.7
50x50		51,266	17,706		113.3 272.2	54.1 674.3 55.7
75x75		50,221	15,823		71.1 271.1	48.4 639.5 48.4

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-16 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn*	Σn* Σn'	Σn* Σn' Σn
2x2						
3x3						
4x4						
10x10	244,460	43,581	16,773	13.6	29.6 238.8	52.6 477.0 57.9
25x25		47,254	12,354		42.9 257.8	35.7 469.9 39.2
50x50		46,478	10,700		30.8 254.8	31.1 449.5 32.3
65x65		47,026	11,689		34.4 257.4	34.3 469.9 36.0

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn* - sum of sample sizes over all strata for primary sample units
Σn' - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-17 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00$, $\alpha = .67$
2.) AE = (.05, .15, .15)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Isoclass Stratification
2.) Cluster size -- as shown
3.) Equal Selection Probability
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2						
3x3						
4x4						
10x10	281,929	43,784	16,822	15.7	29.7 239.9	52.8 479.5 58.0
25x25		47,475	12,400		45.6 258.7	35.8 472.3 39.3
50x50		47,097	10,947		35.2 257.7	32.8 453.4 33.0
65x65		47,289	11,731		36.9 258.2	34.4 472.1 36.1

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees, C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-18 Summary Results of SUMT Executions

MODEL PARAMETERS

1.) $t = 1.00, \alpha = .67$
2.) AE = (.1, .2, .2)
3.) Cost Data Set 2
4.) $\rho = .8$

MODEL VARIABLES

1.) Default Stratification
2.) Cluster size -- as shown
3.) Proportional to Size Probabilities
4.) Subsampling procedure -- as shown

Cluster Size	Total Variable Cost			Numbers of Sample Units		
	STRAT	STRAT2S	STR2SD	STRAT	STRAT2S	STR2SD
	F	F	F	Σn^*	Σn^* $\Sigma n'$	Σn^* $\Sigma n'$ Σn
2x2	24,437			33.9		
3x3	27,798			17.2		
4x4	36,434			12.7		
10x10	216,007	25,850	8431	12.0	20.5 141.0	24.8 265.0 28.6
25x25		26,371	8437		22.1 144.0	24.4 263.8 28.4
50x50		26,645	8286		21.5 145.6	23.6 263.5 28.3
75x75		26,732	7671		19.8 143.6	22.1 166.0 25.3

t - level of probability factor for confidence statements
AE (A B C) - allowable error in decimal form A = basal area, B = number of trees,
C = percent crown closure in forest
ρ - correlation between primary and auxiliary variables
Subsampling method - STRAT - Stratified sampling
STRAT2S - Stratified two stage sampling
STR2SD - Stratified two stage with double sampling
F - objective function or implementation cost
Σn^* - sum of sample sizes over all strata for primary sample units
$\Sigma n'$ - sum of sample sizes over all strata for secondary sample units
Σn - sum of sample sizes over all strata for tertiary sample units

Table H-19 Sensitivity of the model solution to changes in the correlation parameter

MODEL PARAMETERS

1) Probability level for confidence statements, $t = 100\ \alpha \doteq .67$
2) Precision constraints AE = (.10, .20, .20)
3) Cost coefficients data set 1 C = (50, 7, 15, 70, 1500)
   2 C = (50, 7, 15, 180, 0)
4) Correlation -- as below

MODEL VARIABLES (specified for a single run of SUMT)

1) Stratification method -- Default
2) Cluster size, X = 10, Y = 10
3) Selection probability -- proportional to size
4) Subsampling procedure -- Two stage with double sampling

Cost Coefficient Set 1

Percent Change in F	Correlation	Cost F	Sample Sizes Σn*	Σn'	Σn
+ 11.04	.5	27,140	31.9	345.3	33.2
+ 8.35	.6	26,483	30.4	338.9	31.6
+ 4.81	.7	25,616	28.5	329.4	29.7
0	.8	24,441	25.8	314.5	27.2

Cost Coefficient Set 2

Percent Change in F	Correlation	Cost F	Σn*	Σn'	Σn
+19.45	.5	10,071	31.8	292.3	34.6
+14.66	.6	9,667	30.1	286.4	33.1
+ 8.39	.7	9,138	27.8	277.9	31.2
0	.8	8,431	24.8	265.0	28.6

Table H-21 Sensitivity of the model solution to changes in allowable error.

MODEL PARAMETERS

1) Probability level for confidence statements, t = 1.00, $\alpha \doteq .67$
2) Precision constraints - Variable as shown
3) Cost coefficient data set 1 C = (50, 7, 15, 70, 1500)
   2 C = (50, 7, 15, 180, 0)
4) Correlation $\rho = 0.8$

MODEL VARIABLES

1) Stratification method - Default
2) Cluster size, X = 10, Y = 10
3) Selection probability - proportional to size
4) Subsampling procedure - Two stage with double sampling

Cost Coefficient Set 1

Percent Change in F	Allowable Error	Cost F	Σn^*	$\Sigma n'$	Σn
+ 199.45	(.05 .05 .05)	73,188	105.2	3513.9	102.1
+ 21.05	(.05 .15 .15)	29,586	35.7	534.3	35.7
0	(.10 .20 .20)	24,441	25.7	314.5	27.2

Cost Coefficient Set 2

Percent Change in F	Allowable Error	Cost F	Σn^*	$\Sigma n'$	Σn
+ 482.73	(.05 .05 .05)	49,130	108.8	3389.1	108.9
+ 42.63	(.05 .15 .15)	12,025	36.7	458.9	37.6
0	(.10 .20 .20)	8,431	24.8	265.0	28.6

APPENDIX I

Selected Results from Execution of the SUMT Component of the WILLIAM Package for Gray's Harbor Test Site

Tables I-1 to I-6 provide examples of the detailed tabular results of SUMT executions for each of the three subsampling executions. Annotations have been made to the first three tables to define the terms not labeled. Additional characteristics of the SUMT optimization procedure are available but have not been included here.

```
SUBROUTINE READIN --  STRATIFIED SAMPLE ALLOCATION

NCLS =    8          NPAR =    3          X =    2  Y =    2

READIN PRINTON     T =    1.0000


COST COEFFICIENTS =        70.      1500.


CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE
                                 -------MEANS-------------  ----------------COVARIANCE MATRIX----------------------------
                 Nh
OLDGRTH          28607    /      494.68      418.69      246.34/ .25650E+05 -.21287E+05  .46354E+04  .32147E+06  .10438E+04  .17950E+04
2NDGRTH          29393    /      491.00      407.21      251.05/ .22404E+05 -.21205E+05  .44842E+04  .35823E+06  .14868E+04  .18305E+04
HDWD             42206    /      436.90      797.03      264.39/ .18604E+05 -.36267E+05  .47828E+04  .73337E+06  .26080E+04  .24183E+04
NSCFL             7310    /      115.93      323.02       91.81/ .14117E+05 -.60875E+04  .48369E+04  .11729E+06  .27504E+04  .25232E+04
NF               12540    /      193.52      427.56      139.30/ .18901E+05 -.71671E+04  .70027E+04  .19640E+06  .51879E+04  .37919E+04
REPRO            16550    /      214.67      676.46      161.54/ .18356E+05 -.12654E+05  .66126E+04  .39408E+06  .80707E+04  .36044E+04
WATER                0    /        0.00        0.00        0.00/ 0.          0.          0.          0.          0.          0.
URBAN                0    /        0.00        0.00        0.00/ 0.          0.          0.          0.          0.          0.


ALLOWABLE ERROR(I),I=1,NPAR

        1       .100
        2       .200
        3       .200


COMMON BLOCK STRAT -- SUMT INPUTS


NH(I),CH(I),S(H,1),S(H,2),S(H,3),H=1,N

 .28607E+05  .28000E+03  .15000E+04  .16016E+03  .56698E+03  .42367E+02  .29393E+05  .28000E+03  .15000E+04  .14968E+03
 .59853E+03  .43364E+02  .42206E+05  .28000E+03  .15000E+04  .13640E+03  .85637E+03  .49176E+02  .73100E+04  .28000E+03
 .15000E+04  .11882E+03  .34248E+03  .50232E+02  .12540E+05  .28000E+03  .15000E+04  .13748E+03  .44317E+03  .61578E+02
 .16550E+05  .28000E+03  .15000E+04  .13548E+03  .62775E+03  .60037E+02


V(I),I=1,NPAR

 .53850E+07  .15301E+08  .61353E+07
```

Table I-1 SUMT/Stratified Sampling, cluster size 2x2, default stratification, PPS selection probabilities; cost data set 1.

```
IX, IY, T, RHO, AERR(3)
        2         2    1.0000      .1000      .2000      .2000
    280.000       1500.000 <-Cost Coefficients

I, PTOT, VAR, AVAR, RSE, CIHWPC
parameter 1    .538502E+08    .289984E+14    .538502E+07    .100000E+02    .100000E+02
          2    .765042E+08    .234116E+15    .153008E+08    .200000E+02    .200000E+02
          3    .306765E+08    .376418E+14    .613529E+07    .200000E+02    .200000E+02
```

Sample Sizes

N_h

```
**********************************
         5.812
         6.381
        14.407
         2.000
         2.001
         3.464
**********************************
```

Σn_h = 34.066

PTOT = Parameter total for population
VAR = Population variance of the estimator
AVAR = $\sqrt{VAR}$
RSE = AVAR/PTOT
CIHWPC = RSE*T
F = objective function value (total variable cost)
X = Vector of sample sizes these are NSTR values of X

```
*****************************************
   POINT=  40      DOTT=   .7635849E-03      RHO=   .3145612E+00      MAGNITUDE=   .6808026E+02      PHASE= 2
  F=   .2967237E+05     P=   .2964589E+05     G=   .2966766E+05     RSIGMA=  -.2909209E+02     H=  0.
 THE CURRENT VALUE OF X IS
   .5811844E+01       .6380834E+01       .1440735E+02       .2000455E+01       .2001399E+01       .3463659E+01
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
   .1674202E+14       .4195448E+10       .3618543E+14       .3811844E+01       .4380834E+01       .1240735E+02
   .4552930E-03       .1398520E-02       .1463659E+01
```

Constraints
1-3 variance constraint
4- (NSTR+3) minimum sample size, each stratum

Table I-1 continued

```
SUBROUTINE REALIN -- STRATIFIED TWO STAGE SAMPLE ALLOCATION
NCLS =    8          NPAR =    3          X =   10  Y =   10

REALIN PRINTED      T =     1.0000
 20.   70.1500.

CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE

CLOSTH     1776/  10811.65   11294.48    5708.41/  .29182E+07 -.14675E+07  .94807E+06  .1065CE+08 -.11874E+06  .3583CE+06
                                                    .38719E+08 -.49701E+08  .13C55E+08  .866L3E+09  .49819E+07  .56086E+07
2NDGRTH     650/  11815.35   12201.78    6239.45/  .11577E+07 -.12270E+07  .30278E+06  .12111E+08  .74282E+04  .12235E+06
                                                    .54236E+08 -.58821E+08  .11403E+08  .10912E+10  .52695E+07  .50415E+07
HOWD       2147/  10386.81   17441.25    6156.94/  .20796E+07 -.85291E+06  .73905E+06  .17261E+08  .23818E+06  .22816E+06
                                                    .48901E+08 -.71807E+08  .12843E+08  .15524E+10  .96793E+07  .64510E+07
NSCFL       310/   3002.03    6187.49    2048.88/  .12226E+07 -.96466E+05  .44859E+06  .28022E+07  .89667E+05  .18404E+06
                                                    .16493E+08 -.71978E+07  .54646E+07  .17233E+09  .36614E+07  .27889E+07
NF          345/   4962.16   11690.28    3523.61/  .20817E+07  .56894E+06  .83188E+06  .62204E+07  .49187E+06  .36964E+06
                                                    .36606E+08 -.20978E+08  .12801E+08  .55682E+09  .12242E+08  .70402E+07
REPRC       346/   5854.43   14787.31    4083.61/  .16900E+07 -.55762E+06  .63584E+06  .10727E+08  .24535E+06  .28161E+06
                                                    .43596E+08 -.32394E+08  .14677E+08  .86896E+09  .15673E+08  .7826CE+07
WATER         0/      C.CC       C.CC       C.CC/ C.          C.          C.          0.          0.          0.
                                                    0.          0.          C.          0.          0.          0.
URBAN         C/      C.CC       C.CC       C.CC/ C.          C.          0.          0.          C.          C.
                                                    C.          C.          C.          0.          0.          0.

ALLOWABLE ERROR(I),I=1,NPAR

        1       .100
        2       .200
        3       .200

NHINV(1) ,CH(3),D(3),B(3),MHINV,NSTR

 .56306E-03  .20000E+02  .70000E+02  .15000E+04  .92045E+13  .33959E+14  .11301E+13  .18521E+15  .27319E+16  .17690E+14
 .15385E-02  .20000E+02  .70000E+02  .15000E+04  .48914E+12  .51170E+13  .51691E+11  .22957E+14  .46104E+15  .21300E+13
 .46577E-03  .20000E+02  .70000E+02  .15000E+04  .95866E+13  .79568E+14  .15127E+13  .22541E+15  .71559E+16  .29737E+14
 .32256E-02  .20000E+02  .70000E+02  .15000E+04  .11749E+12  .26930E+12  .17686E+11  .15849E+13  .16561E+14  .26802E+12
 .26986E-02  .20000E+02  .70000E+02  .15000E+04  .24778E+12  .74038E+12  .43997E+11  .43957E+13  .66276E+14  .83796E+12
 .28902E-02  .20000E+02  .70000E+02  .15000E+04  .20232E+12  .12841E+13  .33713E+11  .52192E+13  .10403E+15  .93689E+12
 .10000E-01
        6

V(I),I=1,NPAR

 .53850E+07  .15301E+06  .61353E+07
```

Table I-2 SUMT/stratified two stage sampling, cluster size 10x10, default stratification PPS selection probabilities, cost data set 1

```
SUBROUTINE SUMRIZE -- STRATIFIED INC STAGE


IX,IY,T,RHO,AERR(3)
        10          10     1.0000      .1000      .2000      .2000
        20.000           70.000        1500.000          Cost Coefficients

I,PTOT,VAR,AVAR,RSE,CIHYPO
parameter1     .538502E+08     .185631E+14     .430849E+07     .800089E+01     .800089E+01
          2    .765042E+08     .234112E+14     .153007E+08     .199999E+02     .199999E+02
          3    .306765E+08     .244081E+13     .156231E+07     .509286E+01     .509286E+01


*****************************
          2.000          20.751
          2.000           8.526
          2.000          33.586
          2.000           2.003
          2.000           3.234
          2.000           4.051
*****************************
         12.002         144.326


*****************************************
        POINT=  80       DOTT=    .5167160E-02       RHO=    .1449582E+00       MAGNITUDE=    .1089804E+03       PHASE= 2
     F=    .2307163E+05     P=    .2305435E+05     G=    .2306598E+05     PSIGMA=  -.2049248E+02     H=  0.
   THE CURRENT VALUE OF X IS
     .2000300E+01        .2000271E+01        .2000209E+01        .2000239E+01        .2000268E+01        .2000269E+01
     .2075112E+02        .8526073E+01        .3358647E+02        .2002947E+01        .3234304E+01        .4051229E+01
   THE CONSTRAINT VALUES
                       NOT INCLUDING THE NON-NEGATIVITIES
     .1774000E+04        .6479997E+03        .2145000E+04        .3079998E+03        .3429997E+03        .3439997E+03
     .7924888E+02        .9147393E+02        .6641353E+02        .9799705E+02        .9676570E+02        .9594877E+02
     .1043530E+14        .3269993E+10        .3520100E+14        .2998928E-03        .2709238E-03        .3090641E-03
     .2369085E-03        .2682062E-03        .2689752E-03        .1875112E+02        .6526073E+01        .3158647E+02
     .2947246E-02        .1234304E+01        .2051229E+01
```

Constraint

1 - NSTR, NSTR+1 - 2NSTR } maximum n_h^* , n_h' , each stratum

2NSTR+1 - 2NSTR+3 variance constraints

2NSTR+4 - 3NSTR+3, 3NSTR+4 - 4NSTR+3 } minimum n_h^* , n_h' , each stratum

Table I-2 continued

```
SUBROUTINE READIN     STRATIFIED TWO STAGE WITH DOUBLE SAMPLING
NCLS =    8          NPAR =    3          X =   10  Y =   10
READIN PRINTON     T =    1.0000    RHO =     .8000
 50.   7.  15.  70.1500.
CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE
OLDGRTH    1776/  10811.65   11294.48    5708.41/  .29182E+07 -.14675E+07  .94807E+06  .10650E+08 -.11874E+06  .35830E+06
                                                   .58719E+08 -.49701E+08  .13055E+08  .86613E+09  .49819E+07  .56086E+07
2NDGRTH     650/  11815.35   12201.78    6239.45/  .11577E+07 -.12270E+07  .30278E+06  .12111E+08  .74282E+04  .12235E+06
                                                   .54336E+08 -.58821E+08  .11403E+08  .10912E+10  .52695E+07  .50415E+07
POWD       2147/  10386.81   17441.25    6156.94/  .20796E+07 -.85291E+06  .73905E+06  .17261E+08  .33818E+06  .32816E+06
                                                   .48901E+08 -.71807E+08  .12843E+08  .15524E+10  .96793E+07  .64510E+07
NSCFL       310/   3002.03    6187.49    2048.88/  .12226E+07 -.96466E+05  .44859E+06  .28022E+07  .89667E+05  .18404E+06
                                                   .16493E+08 -.71978E+07  .54646E+07  .17233E+09  .36614E+07  .27889E+07
NF          345/   4962.16   11690.28    3523.61/  .20817E+07  .56894E+06  .83188E+06  .62204E+07  .49187E+06  .36964E+06
                                                   .36606E+08 -.20978E+08  .12801E+08  .55682E+09  .12242E+08  .70402E+07
REFRD       346/   5854.43   14787.31    4083.61/  .16900E+07 -.55762E+06  .63584E+06  .10727E+08  .24535E+06  .28161E+06
                                                   .43596E+08 -.32394E+08  .14677E+08  .86896E+09  .15673E+08  .78200E+07
WATER         0/      0.00       0.00       0.00/ 0.         0.         0.         0.         0.         0.
                                                   0.         0.         0.         0.         0.         0.
URBAN         0/      0.00       0.00       0.00/ 0.         0.         0.         0.         0.         0.
                                                   0.         0.         0.         0.         0.         0.
ALLOWABLE ERROR(I),I=1,NPAR
        1       .100
        2       .200
        3       .200
COMMON BLOCK STRAT -- SUMT INPUTS
NHINV(1) ,CH(3),D(3),B(3),MHINV,NSTR
 .56306E-03  .66575E+14  .98349E+15  .63685E+13  .92045E+13  .33590E+14  .11301E+13  .18521E+15  .27319E+16  .17690E+14
 .15365E-02  .82645E+13  .16597E+15  .76681E+12  .48914E+12  .51170E+13  .51691E+11  .22957E+14  .46104E+15  .21300E+13
 .46577E-03  .81149E+14  .25761E+16  .10705E+14  .95860E+13  .79568E+14  .15127E+13  .22541E+15  .71559E+16  .29737E+14
 .32258E-02  .57058E+12  .59619E+13  .96486E+11  .11749E+12  .26930E+12  .17686E+11  .15849E+13  .16561E+14  .26802E+12
 .23986E-02  .15685E+13  .23859E+14  .30167E+12  .24778E+12  .74038E+12  .43997E+11  .43570E+13  .66276E+14  .83796E+12
 .23902E-02  .18789E+13  .37450E+14  .33728E+12  .20232E+12  .12841E+13  .33713E+11  .52192E+13  .10403E+15  .93689E+12
 .10000E-01
       0
V(I),I=1,NPAR
 .53850E+07  .15301E+08  .61353E+07
```

Table I-3 SUMT/stratified two stage with double sampling, cluster size 10x10, default stratification, PPS selection probabilities, cost data set 1.

```
SUBROUTINE SUMRIZE -- STRATIFIED TWO STAGE WITH DOUBLE SAMPLING


IX,IY,T,RHO,AERR(3)
        10         10      1.0000        .8000        .1000        .2000        .2000
        50.000          7.000         15.000         70.000       1500.000


I,PTOT,VAR,AVAR,RSE,CIHWPC
         1    .538502E+08    .139290E+14    .373215E+07    .693062E+01    .693062E+01
         2    .765042E+08    .234102E+15    .153004E+08    .199994E+02    .199994E+02
         3    .306765E+08    .175401E+13    .132439E+07    .431728E+01    .431728E+01



**************************
         5.741          16.347          1.001
         3.954           9.178          1.001
         7.613          20.258          1.000
         2.004           2.007          1.553
         3.056           3.567          1.085
         3.373           4.498          1.009
**************************
        25.750         314.531         27.161



****************************************
     POINT=  53       DOTT=   .4546234E-02      RHO=   .3457386E+00      MAGNITUDE=   .3346120E+04      PHASE= 2
   F=   .2444099E+05     P=   .2444955E+05     G=   .2441921E+05     RSIGMA=   .1781351E+01     H=  0.
 THE CURRENT VALUE OF X IS
   .5740623E+01       .3964323E+01       .7612633E+01       .2004245E+01       .3055674E+01       .3372946E+01
   .1634678E+02       .9177535E+01       .2025750E+02       .2006527E+01       .3567204E+01       .4498493E+01
   .1000519E+01       .1001317E+01       .1000386E+01       .1553189E+01       .1085059E+01       .1009234E+01
 THE CONSTRAINT VALUES
                    NOT INCLUDING THE NON-NEGATIVITIES
   .1736341E+00       .2507114E+00       .1308948E+00       .4957151E+00       .3243615E+00       .2935865E+00
   .5117+13E-01       .9896172E-01       .3936442E-01       .4883736E+00       .2703316E+00       .2122967E+00
   .9383076E+00       .8897228E+00       .9502494E+00       .1454630E+00       .6412770E+00       .7685542E+00
   .1506943E+14       .1375389E+11       .3588781E+14       .3258029E+00       .2477501E+00       .3686394E+00
   .1059051E-02       .1727400E+00       .2035233E+00       .4388259E+00       .3910383E+00       .4506356E+00
   .1626428E-02       .2196684E+00       .2777033E+00       .5182590E-03       .1315448E-02       .3861384E-03
   .3561634E+00       .7839141E-01       .9149160E-02       .4776794E+00       .2442459E+00       .6060704E+00
   .3629067E-01       .9518308E-01       .1187074E+00
```

Constraint

1-3NSTR maximum n_h^* , n_h' , n_h , each stratum

3NSTR+1 - 3NSTR+3 variance constraints

3NSTR+4 - 6NSTR+3 minimum n_h^* , n_h' , n_h , each stratum

6NSTR+4 - 7NSTR+3 degrees of freedon constraint, each stratum

Table I-3 continued

```
SUBROUTINE READIN -- STRATIFIED SAMPLE ALLOCATION

NCLS =    8          NPAR =    3          X =    2  Y =    2

READIN PRINTON     T =    1.0000


COST COEFFICIENTS =       180.        0.


CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE

OLDGRTH       28607     /    494.68    418.69    246.34/  .25650E+05 -.21287E+05  .46354E+04  .32147E+06  .10438E+04  .17950E+04
2NDGRTH       29393     /    491.00    407.21    251.05/  .22404E+05 -.21205E+05  .44842E+04  .35823E+06  .14868E+04  .18805E+04
HDWD          42206     /    436.90    797.03    264.39/  .18604E+05 -.36267E+05  .47828E+04  .73337E+06  .26080E+04  .24183E+04
NSCFL          7310     /    115.93    323.02     91.81/  .14117E+05 -.60875E+04  .48369E+04  .11729E+06  .27504E+04  .25232E+04
NF            12540     /    193.52    427.56    139.30/  .18901E+05 -.71671E+04  .70027E+04  .19640E+06  .51879E+04  .37919E+04
REPRO         16550     /    214.67    676.46    161.54/  .18356E+05 -.12654E+05  .66126E+04  .39408E+06  .80707E+04  .36044E+04
WATER             0     /      0.00      0.00      0.00/ 0.          0.          0.          0.          0.          0.
URBAN             0     /      0.00      0.00      0.00/ 0.          0.          0.          0.          0.          0.


ALLOWABLE ERROR(I),I=1,NPAR

        1       .100
        2       .200
        3       .200


COMMON BLOCK STRAT -- SUMT INPUTS


NH(I),CH(I),S(H,1),S(H,2),S(H,3),H=1,N

 .28607E+05  .72000E+03 0.          .16016E+03  .56698E+03  .42367E+02  .29393E+05  .72000E+03 0.          .14968E+03
 .59853E+03  .43364E+02  .42206E+05  .72000E+03 0.          .13640E+03  .85637E+03  .49176E+02  .73100E+04  .72000E+03
0.          .11882E+03  .34248E+03  .50232E+02  .12540E+05  .72000E+03 0.          .13748E+03  .44317E+03  .61578E+02
 .16550E+05  .72000E+03 0.          .13548E+03  .62775E+03  .60037E+02


V(I),I=1,NPAR

 .53850E+07  .15301E+08  .61353E+07
```

Table I-4 SUMT/stratified sampling, cluster size 2x2, default stratification, PPS selection probabilities, cost data set 2.

```
SUBROUTINE SUMERIZE -- STRATIFIED SAMPLING


IX,IY,T,RHO,AERR(3)
         2           2    1.0000      .1000      .2000      .2000
       720.000               0.000


I,PTOT,VAR,AVAR,RSE,CIHWPC
         1     .538502E+08     .289984E+14     .538502E+07     .100000E+02     .100000E+02
         2     .765042E+08     .234116E+15     .153008E+08     .200000E+02     .200000E+02
         3     .306765E+08     .376418E+14     .613529E+07     .200000E+02     .200000E+02



*****************************
         6.029
         6.539
        13.434
         2.001
         2.074
         3.862
*****************************
        33.940



*****************************************
         POINT=  23        DOTT=    .9163076E-04       RHO=    .4379289E+00       MAGNITUDE=    .2089271E+02       PHASE= 2
       F=    .2443706E+05      P=    .2439802E+05      G=    .2443049E+05      RSIGMA=  -.4175616E+02      H=  0.
     THE CURRENT VALUE OF X IS
       .6029148E+01          .6539386E+01          .1343433E+02          .2000778E+01          .2074355E+01          .3862362E+01
     THE CONSTRAINT VALUES
                           NOT INCLUDING THE NON-NEGATIVITIES
       .1698127E+14          .4384173E+10          .3621897E+14          .4029148E+01          .4539386E+01          .1143433E+02
       .7777381E-03          .7435476E-01          .1862362E+01
```

Table I-4 continued

```
SUBROUTINE READIN  --  STRATIFIED TWO STAGE SAMPLE ALLOCATION
NCLS =    8          NPAR =    3          X =   10  Y =   10

READIN PRINTON      1 =     1.0000
 20. 180.   0.

CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE

CLOGRTH    1776/  10811.65   11294.48    5708.41/  .29182E+07 -.14675E+07  .94807E+06  .10650E+08 -.11874E+06  .35830E+06
                                                    .58719E+08 -.49701E+08  .13055E+08  .86613E+09  .49819E+07  .56C86E+C7
2NDGRTH     650/  11815.35   12201.78    6239.45/  .11577E+07 -.1227CE+07  .30278E+06  .12111E+08  .74282E+04  .12235E+06
                                                    .54336E+08 -.58821E+08  .11403E+08  .10912E+10  .52695E+07  .50415E+07
HOWC       2147/  10366.81   17441.25    6156.94/  .20796E+07 -.85291E+06  .73905E+06  .17261E+08  .33818E+06  .32816E+06
                                                    .48901E+08 -.71807E+08  .12843E+08  .15524E+10  .96793E+07  .64510E+07
NSCFL       310/   3002.03    6187.49    2048.88/  .12226E+07 -.96466E+05  .44859E+06  .28022E+07  .89667E+05  .18404E+06
                                                    .16493E+08 -.71978E+07  .54646E+07  .17233E+09  .36614E+07  .27889E+07
NF          345/   4962.16   11690.28    3523.61/  .20817E+07  .56894E+06  .83188E+06  .62204E+07  .49187E+06  .36964E+06
                                                    .26606E+08 -.20978E+08  .12801E+08  .55682E+09  .12242E+08  .70402E+07
REPRC       346/   5854.43   14787.31    4083.61/  .16900E+07 -.55762E+06  .63584E+06  .10727E+08  .24935E+06  .28161E+06
                                                    .43596E+08 -.32894E+08  .14677E+08  .86896E+09  .15673E+08  .78260E+07
WATER         0/      0.00       0.00       0.00/ 0.          0.          0.          0.          0.          0.
                                                   C.          C.          0.          0.          0.          0.
URBAN         0/      0.00       0.00       0.00/ C.          0.          0.          0.          0.          0.
                                                   0.          0.          0.          0.          C.          C.

ALLOWABLE ERROR(I),I=1,NPAR

        1       .100
        2       .200
        3       .200

NFINV(1) ,CF(3),D(3),B(3),MFINV,NSTR

 .56306E-02  .20000E+02  .18000E+03 0.          .92045E+12  .33590E+14  .11301E+13  .18521E+15  .27319E+16  .17695E+14
 .15395E-02  .20000E+02  .18000E+03 C.          .48914E+12  .51170E+13  .51691E+11  .22937E+14  .46104E+15  .21300E+13
 .46577E-03  .20000E+02  .18000E+03 0.          .95860E+13  .79568E+14  .15127E+13  .22541E+15  .71559E+16  .29737E+14
 .32258E-02  .20000E+02  .18000E+03 C.          .11749E+12  .26930E+12  .17686E+11  .15849E+13  .16561E+14  .26802E+12
 .28986E-02  .20000E+02  .18000E+03 C.          .24778E+12  .74038E+12  .43997E+11  .43570E+13  .66276E+14  .83796E+12
 .28902E-02  .20000E+02  .18000E+03 0.          .20232E+12  .12841E+13  .33713E+11  .52192E+13  .10403E+15  .93689E+12
 .10000E-01
        6

V(I),I=1,NPAR

 .53859E+07  .15301E+08  .61353E+07
```

Table I-5 SUMT/stratified two stage sampling, cluster size 10x10, default stratification PPS selection probabilities, cost data set 2

```
SUBROUTINE SUMRIZE -- SIMPLIFIED INC STAGE


IX,IY,T,RHC,AERR(3)
        10          10     1.0000      .1000      .2000      .2000
        20.000          180.000            0.000


I,PTCT,VAR,AVAR,RSE,CIRRC
         1     .538502E+08     .138143E+14     .371676E+07     .690204E+01     .690204E+01
         2     .769042E+08     .234112E+15     .153007E+08     .199999E+02     .199999E+02
         3     .306765E+08     .173015E+13     .131535E+07     .428782E+01     .428782E+01



*****************************
         5.834           6.963
         2.050           8.141
         6.614           9.940
         2.003           2.003
         2.020           3.134
         2.027           3.912
*****************************
        20.548         141.326



*****************************************
         POINT= 123        DOT=    .3264524E-02       RHC=    .3727360E+00       MAGNITUDE=    .2265165E+03       PHASE= 2
       F=    .2584971E+05      P=    .2575283E+05      G=    .2583517E+05      RSIGMA=   -.6219493E+02      H=  0.
     THE CURRENT VALUE OF X IS
       .5833920E+01         .2050123E+01         .6614229E+01         .2002554E+01         .2020216E+01         .2026785E+01
       .6963187E+01         .6141080E+01         .9939544E+01         .2002871E+01         .3133639E+01         .3912403E+01
     THE CONSTRAINT VALUES
                          NOT INCLUDING THE NON-NEGATIVITIES
       .1770166E+04         .6479499E+03         .2140386E+04         .3079974E+03         .3429798E+03         .3439732E+03
       .9203681E+02         .9185892E+02         .9006046E+02         .9799713E+02         .9686636E+02         .9608706E+02
       .1518409E+14         .3270758E+10         .3591169E+14         .3833920E+01         .5012347E-01         .4614229E+01
       .2553795E-02         .2021625E-01         .2678478E-01         .4963187E+01         .6141080E+01         .7939544E+01
       .2870835E-02         .1133639E+01         .1912403E+01
```

Table I-5 continued

```
SU  TIN   DI      S   IFI   T O  W   DOUB   MP   LOCATION
NCLS =    8          NPAR =    3          X =   10  Y =   10
READIN PRINTON      T =     1.0000    RHO =      .8000
 50.   7.  15. 180.   0.
CLASS NAME,COUNT,(AMEAN(I),I=1,NPAR),COVMATRIX LOWER TRIANGLE
CLOGRTH     1776/  10811.65   11294.48    5708.41/  .29182E+07 -.14675E+07  .94807E+06  .10650E+08 -.11874E+06  .35830E+06
                                                    .58719E+08 -.49701E+08  .13055E+08  .86613E+09  .49819E+07  .56086E+07
2NDGRTH      650/  11815.35   12201.78    6239.45/  .11577E+07 -.12270E+07  .30278E+06  .12111E+08  .74282E+04  .12235E+06
                                                    .54336E+08 -.58821E+08  .11403E+08  .10912E+10  .52695E+07  .50415E+07
HDWD        2147/  10386.81   17441.25    6156.94/  .20796E+07 -.85291E+06  .73905E+06  .17261E+08  .33818E+06  .32816E+06
                                                    .48901E+08 -.71807E+08  .12843E+08  .15524E+10  .96793E+07  .64510E+07
NSCFL        310/   3002.03    6187.49    2048.88/  .12226E+07 -.96466E+05  .44859E+06  .28022E+07  .89667E+05  .18404E+06
                                                    .16493E+08 -.71978E+07  .54646E+07  .17233E+09  .36614E+07  .27889E+07
NF           345/   4962.16   11690.28    3523.61/  .20817E+07  .56894E+06  .83188E+06  .62204E+07  .49187E+06  .36964E+06
                                                    .36606E+08 -.20978E+08  .12801E+08  .55682E+09  .12242E+08  .70402E+07
REPRO        346/   5854.43   14787.31    4083.61/  .16900E+07 -.55762E+06  .63584E+06  .10727E+08  .24535E+06  .28161E+06
                                                    .43596E+08 -.32394E+08  .14677E+08  .86896E+09  .15673E+08  .78260E+07
WATER          0/      0.00       0.00       0.00/ 0.          0.          0.          0.          0.          0.
                                                    0.          0.          0.          0.          0.          0.
URBAN          0/      0.00       0.00       0.00/ 0.          0.          0.          0.          0.          0.
                                                    0.          0.          0.          0.          0.          0.

ALLOWABLE ERROR(I),I=1,NPAR
        1       .100
        2       .200
        3       .200
COMMON BLOCK STRAT -- SUMT INPUTS
NHINV(1) ,CH(3),D(3),B(3),MHINV,NSTR
 .56305E-03  .66675E+14  .98349E+15  .63685E+13  .92045E+13  .33590E+14  .11301E+13  .18521E+15  .27319E+16  .17690E+14
 .15385E-02  .82645E+13  .16597E+15  .76681E+12  .48914E+12  .51170E+13  .51691E+11  .22957E+14  .46104E+15  .21300E+13
 .46577E-03  .81149E+14  .25761E+16  .10705E+14  .95860E+13  .79568E+14  .15127E+13  .22541E+15  .71559E+16  .29737E+14
 .32258E-02  .57058E+12  .59619E+13  .96486E+11  .11749E+12  .26930E+12  .17686E+11  .15849E+13  .16561E+14  .26802E+12
 .28985E-02  .15085E+13  .23859E+14  .30167E+12  .24778E+12  .74038E+12  .43997E+11  .43570E+13  .66276E+14  .83796E+12
 .28902E-02  .18789E+13  .37450E+14  .33728E+12  .20232E+12  .12841E+13  .33713E+11  .52192E+13  .10403E+15  .93689E+12
 .10000E-01
        6
V(I),I=1,NPAR
 .53850E+07  .15301E+08  .61353E+07
```

Table I-6 SUMT/stratified two stage with double sampling, cluster size 10x10, default stratification, PPS selection probabilities, cost data set 2.

```
SUBROUTINE SUMRIZE ...STRATIFIED TWO STAGE WITH DOUBLE SAMPLING

IX,IY,T,RHO,AERR(3)
        10          10       1.0000         .8000         .1000         .2000         .2000
        50.000               7.000           15.000          180.000               0.000

I,PTOT,VAR,AVAR,RSE,CIHWPC
         1    .538502E+08    .137543E+14    .370867E+07    .688703E+01    .688703E+01
         2    .765042E+08    .234074E+15    .152995E+08    .199982E+02    .199982E+02
         3    .306765E+08    .173653E+13    .131778E+07    .429572E+01    .429572E+01


******************************
         6.123          12.895          1.003
         4.139           7.472          1.017
         7.980          16.221          1.002
         2.011           2.030          1.572
         2.101           4.269          1.671
         2.490           5.086          1.459
******************************
        24.844         265.049         28.648


*****************************************
        POINT=  47        COTT=    .3274540E-02       RHO=    .7129607E+00       MAGNITUDE=    .6335551E+03       PHASE= 2
     F=    .8430851E+04      P=    .8438957E+04      G=    .8385934E+04      RSIGMA=  -.3899675E+01      H=   0.
    THE CURRENT VALUE OF X IS
      .6123071E+01         .4139386E+01         .7980008E+01         .2010860E+01         .2100748E+01         .2490184E+01
      .1289503E+02         .7471962E+01         .1622120E+02         .2029988E+01         .4269470E+01         .5086260E+01
      .1002888E+01         .1016593E+01         .1001837E+01         .1572476E+01         .1670682E+01         .1458773E+01
    THE CONSTRAINT VALUES
                         NOT INCLUDING THE NON-NEGATIVITIES
      .1627537E+00         .2400432E+00         .1248474E+00         .4940739E+00         .4731225E+00         .3986865E+00
      .6754928E-01         .1238337E+00         .5164771E-01         .4826138E+00         .2242211E+00         .1866081E+00
      .9195714E+00         .8498445E+00         .9365184E+00         .1433261E+00         .3643368E+00         .4888996E+00
      .1524412E+14         .4132668E+11         .3590528E+14         .3366833E+00         .2584183E+00         .3746868E+00
      .2700251E-02         .2397898E-01         .9842329E-01         .4224507E+00         .3661663E+00         .4383523E+00
      .7386163E-02         .2657789E+00         .3033919E+00         .2879326E-02         .1632180E-01         .1833861E-02
      .3640601E+00         .4014420E+00         .3144923E+00         .5114605E+00         .2870840E+00         .6247499E+00
      .5124168E-01         .1452215E+00         .1741482E+00
```

Table I-6 continued

To be published in Proceedings of the 11th International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, 25-29 April 1977

USE OF MULTISPECTRAL DATA IN DESIGN OF FOREST SAMPLE SURVEYS[1)]

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ABSTRACT

The use of multispectral data in design of forest sample surveys using a computer software package, WILLIAM, is described. The system allows evaluation of a number of alternative sampling systems and, with appropriate cost data, estimates the implementation cost for each.

---

1. INTRODUCTION: The Resource Management Context

Remote sensing data sources, including satellite data and conventional aerial photography, as well as direct measurement on the ground are logical inputs for both design and implementation of information production systems to meet management information needs. It is recognized that sampling plays an important role in generating relevant information for managing large geographic populations. The central problem, therefore, is to define the kind and amount of sampling and the place of remote sensing data sources in that sampling system to do the best possible job of meeting the manager's informational needs.

Perhaps the most significant recent event which shows the increasing importance of implementing comprehensive procedures for describing and monitoring wildland systems, is the passage of the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 and related legislation such as the Multiple use-Sustained Yield Act of 1960 and the National Environmental Policy Act. This legislation is directed primarily toward management activities of the US Forest Service, but the implications for other federal and state agencies as well as industrial and non-industrial private lands are present. In particular, the RPA specifies procedures to be followed in developing comprehensive policies and programs with respect to wildland management and requires frequent resource assessments to evaluate progress toward these ends. The necessity to consider all the varied uses and products associated with these lands has shown the need for extensive broadly-based information on a variety of wildland characteristics including forests, range, fish and wildlife, recreation and wilderness, land, and water. It is not at all clear what type of information production procedures will evolve to meet these needs, but the strong implication is that sampling systems will play a significant role and that multiple characteristics will be of interest. With this premise, a systematic procedure for evaluating sampling alternatives, where the objective is to estimate several parameters, is of obvious importance.

A wildland resource system may be partitioned into two interrelated subsystems: the forest ecosystem and the management system, as shown in Figure 1. The ecosystem is the physical entity to be managed and is defined by geographic

[1)] This study was funded by NASA Contract 9-14552

limits. Man's activities and efforts to manipulate and control the ecosystem represent the management system. Both may be viewed as composed of a number of subsystems. In Figure 1, the management system is shown as interacting with the ecosystem primarily through the information system and direct applications of treatments. It is the information system which provides policy-makers and decision-makers with the estimates of current conditions so that informed management decisions may be made and appropriate treatments applied to the ecosystem. Sampling systems are logically implemented within the scope of information systems as primary information production tools. It is this operating framework which must be kept in mind in planning and designing sample survey systems to meet the informational needs of managers.

2. METHOD: Formulation of the Multivariate Survey Planning Model

Given the important role of sampling for resource management and the increasing emphasis on multivariate sampling applications, it is evident that a formal planning mechanism is needed to document and improve the selection of techniques and procedures to be used in meeting estimation objectives. One approach to providing such a mechanism for multivariate survey design is the planning model developed in this study. Aldred (1971) developed a planning model using a population representation derived from a large sample of photo measurements taken over a 25,000 acre test site in Ontario, Canada. The model was not spatially referenced and was limited to a univariate case for estimation of timber volume. In the present application a spatially-referenced population model is derived and multivariate estimation objectives are assumed. The planning Model is formulated as a tool for use in making inferences about how best to sample a particular population to meet specific multivariate information needs. Its objective is to produce an evaluation of alternative sampling systems based on an analysis of spatially-referenced population data.

For this study the population representation is based on satellite multispectral data combined with supplementary information on a set of resource parameters to be estimated by the sample survey. One result of the analysis would be an estimate, or prediction, of the implementation cost for each alternative sampling system. Then, based on estimates for a set of alternatives, inference can be made as to which alternative provides the most cost effective way to sample the population from which the population model was derived.

Two major premises are the basis for the approach used in the planning model. The first is that the population representation, based on satellite and other data, reflects the real-world population with sufficient realism that inferences about alternative sampling systems will be valid for the actual population to be sampled. This hypothesis must go untested since the data required to test it would be impractical to obtain. It is precisely in cases where information is scarce and subject to great uncertainty that sampling is an important tool. Second, the performance measure for alternative systems is the cost of implementing a given alternative system. System cost combined with constraints on system performance, leads to the formulation of a particular model for the allocation of effort. This performance measure, which is actually "minimum cost for informational requirements", is widely used in sample survey design.

Figure 2 shows the major components of the planning model. It consists of a set of FORTRAN computer programs, collectively known as the WILLIAM package, implemented on a CDC 7600 computer. Major inputs, a spatial class assignment file and associated class statistics, as well as output results, specifications for alternatives and a spatially-referenced sampling frame, are also included.

The spatial class assignment file is a map of the population with a class assignment for each element of the map. This file is produced by prior analysis of satellite multispectral data using established discriminant analysis or

classification procedures. In the most common application each element, or cell, in the map is assigned to a particular land use or vegetation type, e.g., water, urban, bare, hardwood forest, conifer forest, etc., based on the spectral data recorded for the cell. Class structure must be consistent with the needs of the manager. Statistics for each class represent a synthesis of other data sources and summarize information for the parameter set to be estimated and include a mean vector and associated covariance matrix.

Program SIMULATE combines the two input files and generates individual parameter values for each element in the population. Simulation is based on an assumed multivariate normal distribution for each class with known mean vector and covariance matrix. The resultant map file contains the class assignment and simulated parameter set for each element in the population.

Program CLUSTER collapses the population representation into sampling units formed as clusters of individual elements. The stratification of sampling units, by assigning clusters to the class with the plurality of elements within the cluster, is accomplished and summary statistics including variance components for each stratum are derived. These statistics depend on a number of specifications which describe the nature of the sampling system to be considered.

Program SUMT uses the summary statistics in an allocation procedure to determine the minimum-cost allocation of sample sizes for a specific sampling strategy and then summarizes system cost and sample sizes (Mylander et al, 1971).

2.1 The Population Representation

The population representation, produced by program SIMULATE, provides the starting point for the planning process. It must preserve the spatial distribution characteristics, a key feature of geographic populations, which may have a significant impact on the sampling methods used. In addition, if the data base has been well designed and maintained, available and pertinent data for the population will be readily available. As was seen in the description of program SIMULATE the generation of a detailed spatially-referenced population model requires two very specific kinds of data inputs: 1) a grid-type geographic data base, with class assignments for each cell; and 2) supporting data which, for class, provides information on the parameters to be estimated.

Most geographic data base structures use either the polygon or grid approach. The first uses a series of polygons, with coordinates of vertices in some convenient system, to code information on location of the data elements. The major advantage is that less data storage space is required, but this is offset by the necessity of using more complicated analysis methods. If the area is partitioned into mutually-exclusive cells, data elements may be assigned to each unit in the population. Size, number and shape of the cells determines how much detail is reflected in the data base. A 40-acre cell size would give a very different representation than a 4-acre size. A major disadvantage of the grid system is that more storage is required since each element in the population must be identified and labeled; however, this is offset by simplier analysis methods. A cell-by-cell class assignment, or stratification, is an excellent tool for evaluating spatial distribution as it influences sampling methods. In this study such a digital data base is available as the result of a discriminant analysis of multispectral data, acquired by satellite. Each cell, roughly one acre in size, is assigned to one class in a land use and vegetation classification scheme. Complementing this partitioning into land uses and vegetation classes are sample data providing estimates of specific parameters of interest for each of the classes.

The supporting data for each land use class may be obtained from special pilot surveys, or from previous in the same area. This information, representing available knowledge of the parameter set to be estimated, combined with

appropriate assumptions about the probability distribution of the variables over the population makes it possible to generate individual cell values by simulation, while preserving average characteristics and spatial distribution influences. This technique is very useful where population sampling units are likely to be clusters of cells rather than individual cells since the variability due to simulation is reduced by clustering. The most obvious distribution for simulation is the multivariate normal, which is easily simulated (Naylor, et al., 1966). Others derived from the multivariate normal, including the multivariate chi-squared and Student'st distribution could be simulated to account for some types of departures from normal. With a cell-by-cell population representation, summaries are easily made to obtain variance components required for the sampling alternatives to be evaluated.

2.2 Allocation of Effort

Answering the questions; How to sample? and at what cost?, are the goals of the allocation of effort component. It requires population summary statistics as input and produces, for a given alternative sampling system, the optimum sample sizes and allocations as well as the implementation cost. To achieve this goal requires, more specifically, 1) mathematical representations of variance relationships and sampling costs, 2) estimates for cost coefficients, 3) estimates of population variability, and 4) a method for finding the least cost allocation of sampling resources.

If mathematical models for the cost and variance relationships can be obtained for particular sampling schemes, mathematical programming provides a method for allocating sampling resources. The mathematical programming problem is formulated in general terms as: minimize the objective function subject to a set of constraint functions (Fiacco and McCormick, 1968; Hillier and Lieberman, 1967). Special cases of the formulation are obtained depending on restrictions on the form of the objective and constraint functions. For the planning model formulation the objective function is a cost function and the constraints are variance functions for each parameter. Since these functions are generally not linear, linear programming is not appropriate. However, the class of problems encountered in allocating sampling effort conform to the assumptions of the convex nonlinear programming problem, and for this problem general and unique solutions have been shown to exist (Fiacco and McCormick, 1968). With the solutions to the allocation problem it is possible to identify the optimum sampling design (among the alternatives considered) while still meeting the constraints imposed.

In summary, the planning model utilizes a population representation which is derived from the data base of the information system and it incorporates as much of the basic data as is possible including simulation of certain detailed values on a unit-by-unit basis. This representation then forms the basis for generating specific inputs to an allocation model, a convex nonlinear programming problem formulated for a specific sampling system. The resulting allocation of effort minimizes the associated cost function. With these basic elements, the scope of the model is limited only by the alternative systems which can be formulated for allocation and by the details of cost or other comparisons which are possible among alternatives.

3. RESULTS: The Quincy Ranger District Study

3.1 Data Inputs

As a result of a 1974 survey for the entire Plumas National Forest, conducted utilizing Landsat multispectral data, large-scale photography, and ground measurements (Titus et al, 1975) a data base of the type required for the planning model was available. The gridded data base structure generated by the

Landsat multispectral scanner system (NASA, 1971) was used in the population model. All other data sources were transformed to the Landsat base. This base is made up of a set of picture elements (pixels) which contain a vector of specific observations made by the scanner at a particular point in time. The on-the-ground area covered by each pixel varies according to parameters associated with the satellite orbit and its relationship to the area scanned. For the Plumas NF it has determined empirically that the area represented by each pixel is a little more than one acre. Individual cells are referenced by an (x,y) coordinate where each point is one pixel. To identify the study area explicitly and to delete all internal blocks of private ownership, an ownership base map was digitized into a local (x,y) coordinate system. This local system was then transformed to the Landsat system using mathematical functions based on least squares regression analysis of a set of control points located in both coordinate systems.

With the source data and study area combined, a maximum likelihood discriminant analysis was performed to assign each pixel in the population to a vegetative or land-use class according to a structure determined by the training areas. As required by discriminant analysis, training areas or examples of particular classes of vegetation and land use are required on which to base the rules for assignment of individuals to specific classes. For the study area two separate analyses were made, because the study area was covered by portions of two Landsat data files, each with 50 to 60 examples of various vegetation and land use categories. Further aggregation of vegetation classes into 17 broad vegetation classes was made by interpreting each of the training areas in light of the desired stratification scheme which included three classes of vegetation (mixed conifer, east-side pine, and true fir) and within each vegetation class, five classes of vegetation conditions (regeneration, immature, mature, overmature, and poorly stocked) were recognized. Two other classes were specified, hardwoods and a residual of all other classes.

Associated with each of the classes are a number of variables important for management. Depending on the particular ecosystem component to be managed the set could be limited to a few major variables. For example, the 1974 inventory concentrated on variables important for timber management, and therefore, many variables useful in managing such components as recreation, watershed, wildlife, or range were not included. Still, a basic approach to a number of resource values depends on the condition and distribution of the vegetation components. For this reason it is considered appropriate to use as parameters, in the verification and application of the planning model, three characteristics which describe the "tree component" of vegetation. The three are number of trees, basal area, and basal area growth. The last two are highly correlated with the volume and volume growth. At the same time they are basic physical measures of the vegetation component which could be related to other management needs. Number of trees combined with total basal area gives an indication of the relative size of the trees. The sample data from the 1974 inventory provided estimates of the mean vector and covariance matrix for each vegetation class.

Selection of these parameters is not to imply in any way that the planning model is limited to timber related parameters. If data is available any parameter set could be used.

In addition to the cell-by-cell vegetation class assignment and their parameter estimates by class, other data inputs are required including 1) required precision levels, 2) cost components of the sampling activities, and 3) correlation between measurements taken on photographs and on the ground. Alternative values for inputs listed above can be used to evaluate sensitivity of the model to input parameters.

With the population model specified it is possible to evaluate the sampling effort required to meet desired precision levels for each of a number of alternative sampling systems. It is obvious that time and money constraints on the planning phase, as well as the limitations of the planning model, will limit the total number of alternatives which might be evaluated. Nonetheless, by careful selection of the few alternatives to be examined, it is possible to gain valuable insights about the best way to allocate sampling resources in situations where we must act on the basis of incomplete and uncertain information.

Analysis of sampling systems for the Quincy Ranger District was based on alternatives obtained as specific combinations of the following factors: 1) level of confidence and precision, 2) cost components, 3) sampling strategy (single stage, two stage, or two stage with double sampling), 4) selection probability, 5) cluster size, and 6) correlation between measurement variables.

3.2 Results

The only conclusion which holds over all levels of factors examined here is that probability proportional to size (PPS) sampling requires a lower cost than equal probability sampling, and that a "large" primary sampling unit (PSU) is better with PPS sampling while a small PSU size is better with equal probability sampling. These conclusions must be qualified by the limits of this particular population model and the range of PSU sizes evaluated. However, the implication seems to be that regardless of relationships among the variables themselves, the larger PSU sizes strengthen the relationship between the size variable used for the selection probability and the magnitude of parameter totals by PSU. Conclusions about which alternative system is the best must be qualified by the particular factors and levels which are tested.

To complete the planning process and select the optimum system from among the alternatives requires specifications for sampling system performance in addition to inputs which define the population model and sampling system characteristics. For example, if the system performance constraint were to achieve estimates with allowable errors of $\pm$ 10 percent with probability level at 95 percent for each parameter, the optimum survey alternative would be estimated to cost \$23,190 and its basic elements would be 1) PSU size of 60 x 6 pixels, 2) selection probabilities proportional to PSU size, and 3) stratified two stage with double sampling. This alternative would be optimal with respect to the planning model which makes a number of specific assumptions about the population characteristics and cost of implementing various sampling alternatives. For this reason there is always a certain element of uncertain with respect to whether the alternative selected is optimal with respect to the real world population. Preparation of an implementation plan, outlining in detail the operational aspects of the system, would complete the planning process.

Additional details on the results of this application of the planning model, as well as the background for the model development, are provided by Colwell and Titus (1976) and Titus (1977).

4. CONCLUSION

The planning model developed here represents a formalization of the interrelationships which must be considered in planning sample surveys for multivariate applications. As with any model, assumptions are required in order to simplify the "real world" complexities so that a workable model can be formulated. But even with assumptions, some of which require additional research to evaluate their importance, the planning model provides an important mechanism for evaluating the various factors, data and components of a sample survey system. Without this formal planning mechanism, survey design is largely

relegated to experience, hunches and guesses. This is especially true when large multi-purpose surveys are contemplated.

A significant requirement for the successful implementation of a planning model of this kind is the availability, in a useable form, of considerable prior information about the population to be surveyed. A "data base management system", is probably the only way to insure that this kind of information is accumulated and maintained over time. If this level of information is available and its quality is improved as time passes (and more data are acquired), the planning effort becomes more effective and the efficiency of the sampling effort should increase. The Landsat population model used in the Quincy Ranger District study meets this requirement and represents a unique application of a remote sensing data source to planning for sample surveys.

References

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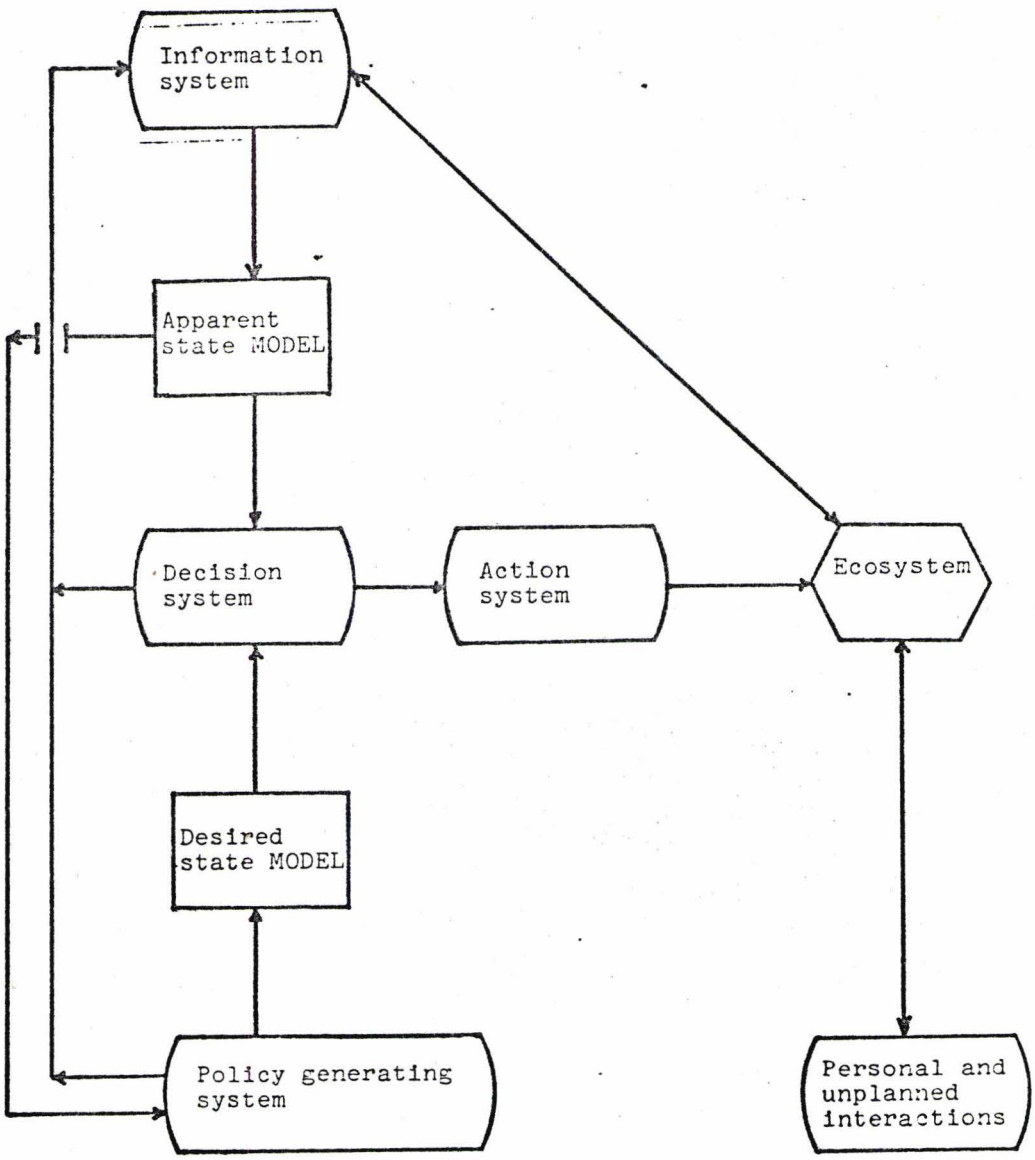

FIGURE 1. MANAGEMENT SYSTEM and the object of management, the ecosystem.

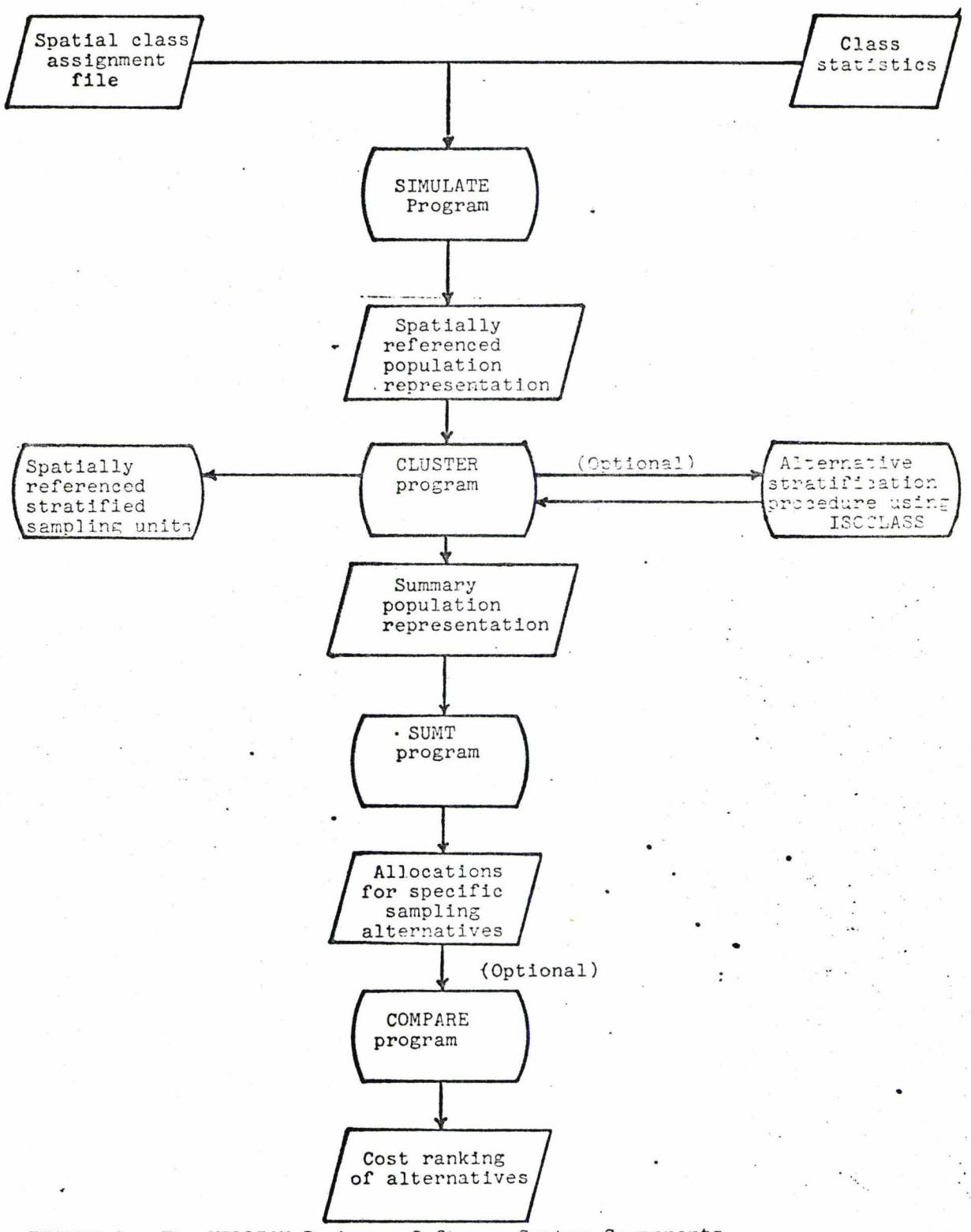

FIGURE 2. The WILLIAM Package, Software System Components

APPENDIX K

Gray's Harbor Class Statistics

The data tabulated in this appendix was provided by ESL, Inc., Sunnyvale, California. It is based on analysis of sample data in each of the six classes. The sample data consists of photo interpretation data. Seven parameters are included for each class including a mean vector and covariance matrix. The line identified in the Item No. column defines the values as follows:

10 - mean values, class 1
11-17 - covariance matrix, class 2
20 - mean values, class 2
21-27 - covariance matrix, class 2
.
.
.
80 - mean values, class 8
81-87 - covariance matrix, class 8

The parameters provided are:

1) DBH average stand diameter,in inches
2) BA average stand basal area, in square feet
3) STEMS average number of trees per acre
4) CCCON average percent crown closure, conifers
5) CCHWD average percent crown closure, hardwoods
6) CCOTHER average percent crown closure, others
7) CCFOR average percent crown closure, forested

PARAMETERS

	Item No.	DBH 1	BA 2	STEMS 3	CC CON 4	CC HWD 5	CC OTHER 6	CC FOR 7
1	10	16.54	135.29	101.92	56.73	8.37	34.90	65.10
	11	32.15						
	12	224.68	6218.90					
	13	-106.71	-4933.18	75333.78				
	14	48.76	1280.46	-292.35	560.27			
	15	-38.01	-392.96	426.51	-254.06	256.64		
	16	-10.74	-888.65	-135.03	-306.09	-2.53	308.71	
	17	10.74	888.65	135.03	306.09	2.53	-308.71	308.71
2	20	12.49	120.75	88.51	46.15	15.98	37.87	62.13
	21	21.72						
	22	148.43	4837.20					
	23	-154.73	-4493.79	88007.16				
	24	45.40	1220.69	-1523.87	587.09			
	25	-23.12	-133.14	1868.13	-305.71	505.80		
	26	-22.22	-1088.73	-338.45	-281.22	-199.84	481.36	
	27	22.22	1088.73	338.45	281.22	199.84	-481.36	
3	30	10.57	111.78	221.43	32.47	36.99	30.54	69.46
	31	11.13						
	32	67.78	3750.34					
	33	-407.10	-9856.30	214304.18				
	34	6.89	209.06	1687.01	750.76			
	35	6.50	744.85	-1240.94	-612.36	971.57		
	36	-13.34	-954.32	-433.77	-138.76	-358.83	497.74	
	37	13.34	954.32	433.77	138.76	358.83	-497.74	497.74

	Item No.	1	2	3	4	5	6	7
4	40	12.75	19.69	88.57	13.43	7.43	79.14	20.86
	41	22.78						
	42	203.95	2538.14					
	43	-232.24	-1361.60	21629.58				
	44	4.45	264.75	760.50	289.34			
	45	32.51	661.86	-133.83	-16.67	306.25		
	46	-37.01	-926.26	-627.93	-272.75	-289.74	562.64	
	47	37.01	926.26	627.93	272.75	289.74	-562.64	562.64
5	50	12.33	35.96	93.75	20.46	10.92	68.62	30.86
	51	28.41						
	52	161.79	2813.24					
	53	-219.12	-1612.90	23768.39				
	54	51.66	630.01	507.42	524.87			
	55	-21.02	602.23	451.16	-42.40	371.72		
	56	-30.59	-1232.15	-958.88	-482.52	-329.69	-812.25	
	57	30.59	1232.15	958.88	482.52	329.69	812.25	812.25
6	60	10.84	39.85	212.67	19.80	17.97	62.23	37.77
	61	13.05						
	62	29.27	2606.69					
	63	-469.83	-2199.60	113191.87				
	64	8.42	335.22	2590.17	421.48			
	65	-9.82	776.99	252.25	-117.37	548.96		
	66	1.47	-1112.89	-2835.88	-305.74	-424.64	725.22	
	67	-1.47	1112.89	2835.88	305.74	424.64	-725.22	725.22